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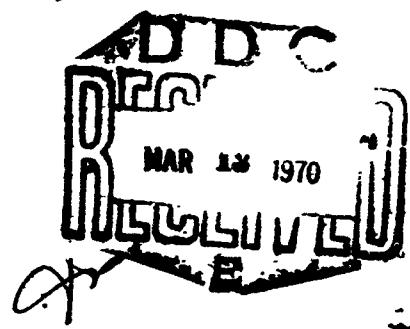
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DC
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NUMBER D2-113073-1

TITLE: MATERIALS COMPATABILITY WITH
LIQUID ROCKET PROPELLANTS



(See form 1411)

SEATTLE, WASHINGTON

REV LTR
THE ~~BOEING~~ COMPANY

JRC

CODE IDENT. NO. 81205

NUMBER D2-113073-1

TITLE: MATERIALS COMPATABILITY WITH
LIQUID ROCKET PROPELLANTS

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ABSTRACT

This document presents hazard documentation in the area of materials compatibility with liquid rocket propellants. The information contained herein has been collected and extracted in part from handbooks, specifications, technical reports, books, journal articles and manuals, to aid the Safety Engineer in the survey of such hazard data.

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KEY WORDS

Compatibility
Propellant
Oxidizer
Hazard
Safety
Materials
Metals
Nonmetals

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1.0 INTRODUCTION

Selecting materials to be used in conjunction with liquid propellants is a safety concern, due to the highly reactive nature of propellants. Therefore, this document is prepared to assist both the designer and the safety analyst in determining what materials are or are not compatible with a specific liquid propellant. In some cases the data may be only a point of departure in the determination of compatibility. Such is the case where only general compatibility conclusions are drawn pertaining to certain classes or chemical families of materials. It is, therefore, unsafe to predict the compatibility behavior of a new product, based on generalized conclusions. In other cases, the compatibility data may be conditional and would therefore require verification of compatibility before use. To emphasize the care that must be exercised in using the data provided herein, it is pointed out that even materials inert to a particular propellant can be rendered unsafe by minute amounts of processing additives, pigments, etc., that may be used in one manufacturer's process and not in another's. Compatibility data is only considered valid when the material studied or tested can be specifically identified by a precise chemical composition or by a manufacturer's specific identification of the material and its process of manufacture, or by both.

For the purpose of identifying incompatibility, the observed reaction between liquid propellants and incompatible materials can be broadly grouped by type of material and speed of reaction. These groups are defined below:

- a. Slow chemical or electrochemical reaction between metals and the propellants leading to corrosion and loss of strength of the metals and/or degradation of the propellants.
- b. Slow chemical reaction between nonmetals and the propellants, leading to degradation and loss of strength.
- c. Rapid chemical reaction between all types of materials and the propellant, leading to explosion or fire.

The following important incompatibility considerations have been established within the text and are summarized as follows:

- a. Gold, nickel and gold/nickel alloys, even in minute amounts, can cause catalytic decomposition of UDMH, hydrazine, or ammonia-hydrazine blend fuels at temperatures in excess of 130°F (55°C).

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- b. Chlorinated fluorocarbon lubricants can react violently when used with aluminum or aluminum powder. These same lubricants will react with hydrazine when used with stainless steel; however, this is a decomposition reaction and not violent.
- c. Molybdenum in alloys in excess of 0.5 percent can react violently when used in contact with hydrazine, UDMH, ammonia, or ammonia-based fuels where temperatures exceed the system fluid boiling point.
- d. Fluorinated hydrocarbons can react violently with high pressure or liquid oxygen.
- e. Titanium can react violently with strong oxidizers if the oxidizer penetrates the oxidized surface layer.
- f. Nitrogen tetroxide with a water content in excess of 2.5 percent can accelerate titanium intergranular corrosion to the point of violent reaction.
- g. Free chloride ions in nitrogen tetroxide can cause an acceleration of intergranular corrosion in titanium.

2.0 PURPOSE

The purpose of this document is to collect and publish, in one document, the chemical and physical compatibility of rocket propellants with the metallic and nonmetallic elements of a design system. This research will provide the System Safety Engineer with fundamental background information which can be used as a guide to provide safety criteria and reduce the time required to survey hazard data. Source material is referenced along the right hand edge of the textual pages and listed in Section 4.0.

3.0 SCOPE

Propellants as considered herein include: liquid propellants (fuels and oxidizers), propellant mixtures, propellant components, and ignition starting fluids. The data presented has been collected and extracted in part from sources such as handbooks, specifications, technical reports, books, journal articles, and manuals.

New areas of interest will be covered and the contents herein updated as the need becomes apparent.

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5.0 DEFINITIONS

Anhydrous: Containing no water; loosely used here to denote that water content is below a certain limit.

Autoignition temperature: The lowest temperature at which fuel in contact with air or oxidizer will ignite - with no aid from an outside source, such as a spark or flame - and will continue to support combustion.

Compatibility: The ability to mix or coexist together without adverse reaction.

Hydrolyze: Subjected to chemical decomposition by which a compound is resolved into other compounds by taking up the elements of water.

Hygroscopic: The property of readily absorbing moisture from the atmosphere.

Hypergolic: Descriptive of certain fuels and oxidizers that are self-igniting upon contact with each other.

Monopropellant: A mixture or a compound containing all elements necessary for its combustion or decomposition.

Oxidizer: Material necessary to support combustion of a fuel.

Plasticizer: Any of a group of substances which are used in plastics, to impart softness and viscous quality to the finished product.

Polymerize: To produce a compound (polymer) formed by two or more molecules of a simpler compound, the relative amount of each element remaining the same.

Propellant: Fuels, oxidizers, and monopropellants.

Pyrophoric: Spontaneously ignitable in air.

Reducing Agent: A substance that causes another substance to undergo reduction and is oxidized in the process.

SECTION 6 - AEROZINE 50

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		<u>Reference</u>
6.0	AEROZINE 50 (50% N₂H₄ - 50% UDMH)	
6.1	Aerozine 50 is a mixture of commercial, concentrated hydrazine and commercial unsymmetrical dimethylhydrazine (UDMH) in approximately equal proportions by weight. The propellant described herein conforms to MIL-P-27402 (USAF), 24 Feb. 1967.	
6.2	Nature	
6.2.1	Hydrazine and UDMH are miscible in all proportions. However, because of their different densities, they are easily layered, UDMH above hydrazine.	Y
6.2.2	The freezing of Aerozine 50 causes separation of the completely blended components.	Y
6.2.3	Physical and thermodynamic properties of Aerozine 50 are intermediate between those for hydrazine and UDMH.	Y
6.2.4	The vapor over liquid Aerozine 50 is composed almost entirely (> 90%) of UDMH, thus the flammability hazards of the vapor mixture are the same as those of UDMH.	Y
6.2.5	Hydrazine is the most reactive and unstable component of Aerozine 50, thus the other characteristics of the liquid mixture with respect to fire and explosion are between those of the two components.	Y
6.2.6	UDMH vapor is flammable in air over a very wide range of concentrations, 2.5% to 95% by volume. The flammability limits for hydrazine vapor in air are 4.7% to 100% by volume.	C, Y
6.2.7	Aerozine 50 is insensitive to mechanical shock and vibration.	Y
6.2.8	Aerozine 50 will also ignite on contact with some solid-propellant formulations, e.g., a double-base propellant, but with considerable delay.	Y
6.2.9	Aerozine 50 is hypergolic with oxidizers such as nitrogen tetroxide, white and red fuming nitric acids, hydrogen peroxide, and chlorine trifluoride.	Y

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	<u>Reference</u>
6.2.10 Aerozine 50 is hygroscopic. To prevent degradation of performance, Aerozine 50 must be stored and handled in closed, dry equipment under a blanket of dry nitrogen.	Y
6.3 Metals Compatibility	
6.3.1 The alloys used in most applications with Aerozine 50 are the stainless steels.	Y
6.3.2 Caution must be exercised when using nickel, gold, and gold/nickel alloys within the Aerozine 50 system at temperatures in excess of 130°F (55°C) due to reported catalytic decomposition of the fuel. It must also be emphasized that certain alloys of nickel (i.e., Aerobrazz, K-Monel, and Inconel X) exhibit good resistance to this fuel and until tested under exact service conditions, general conclusions of incompatibility must not be drawn for this family of materials.	H, The Boeing Company, 2-5023
6.3.3 Steels containing more than 0.5% molybdenum (AISI 316, AM 350, and AM 355) can be used for Aerozine 50 service at temperatures not to exceed 160°F.	Y
6.3.4 The cobalt-chrome alloys, Haynes Stellites 6K, 21, and 25, exhibit good chemical resistance to Aerozine 50.	B
6.3.5 Carbon steels are not recommended for Aerozine 50 service. If used, care must be exercised because of the possible catalytic decomposition of the fuel blend due to rust.	Y
6.3.6 All classes of aluminum alloys are considered satisfactory for unlimited exposure to Aerozine 50. Aluminum alloys are protected from corrosion by naturally occurring oxide films on their surfaces.	B, Y
6.3.7 Welded aluminum alloy 2014-T6 must be limited to transient or limited contact, due to stress cracks found after exposure to this fuel blend.	B
6.3.8 Titanium and nickel alloys (at ambient temp.) are satisfactory for unlimited exposure to Aerozine 50.	Y, AG
6.3.9 Alloys of copper may be used only in specific applications upon the advice of a metallurgist.	Y

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<u>Reference</u>		
6.3.10	Alloys of magnesium and zinc shall not be used.	Y
6.3.11	All metallic coatings, except zinc, gold, and cadmium, are satisfactory for Aerozine 50 service. Coatings used successfully include the following:	Y
a. anodize coatings on aluminum	e. silver	
b. magnesium anodize	f. crack-free chromium	
c. electro-nickel	g. tin	
d. electroless nickel	h. hard-facing alloys	
6.3.12	Brazing alloys, LM Nicrobraz (AMS 4775), Aerobraz-1 (nickel-gold-palladium), and C-62 (manganese base) are satisfactory for exposure to Aerozine 50.	Y
6.3.13	The silver solders may be used for specific applications, depending upon the results of a metallurgical evaluation in each case.	Y
6.3.14	The information below is related to conditions of long-term contact (tested at 120°F for 14 days) between the materials and Aerozine 50 and does not necessarily have a bearing on situations involving brief or intermittent contact. In addition, the information presented should be collated with the compatibility data given above. The following is a listing of metals according to their effect on stability (weight-loss ratio) of Aerozine 50:	Y, AG
a. Materials for general use: (Long-term storage)		
<u>Aluminum Alloys</u>		
1100	6061	
2024	6066	
3003	7075	
4043	7079	
5056	356	
5086	M-516	
5456	M-517	

ReferenceFerrous Alloys

303	AM-350
304L	17-7 PH
316	PH 15-7 Mo
347	N-155

Titanium Alloys

75A
A110 AT
C120 AV
B120 VCA

Copper Alloy

Beryllium-Copper (Berylco 25)

Nickel Alloys

K-Monel
Inconel X

Brazing Alloy

Aerobraze (AGC-44077)

b. Materials for limited use: (Weight-loss ratio greater than 3.0 but less than 6.0)

Aluminum Alloy

5254

Ferrous Alloys

301	440C
302	17-4 PH
321	AM-355
410	

Copper Alloy

70/30 Brass

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Reference

c. Materials not recommended:

Ferrous Alloys

4130

4140

A-286

Magnesium Alloy

HK31A

Nickel Alloy

Inconel 713C

6.4 Nonmetal Compatibility

6.4.1	Several nonmetallic materials are satisfactory for service with Aerozine 50: Diamine Nylons, Teflon, certain butyl rubber compounds, graphite, and some silicone base greases have proved most successful.	Y
6.4.2	Nylon and butyl rubber are being used for most dynamic seals.	Y
6.4.3	Nylons per MIL-P-17091-B (Zytel 31, 63, and 101) vary in composition and are highly inert to most solvents; however, the resistance of these nylons to Aerozine 50 is limited to 90 to 120 days at 70° to 80°F. At 160°F, the nylons failed within 30 days.	Y
6.4.4	Polyethylene is being used and polypropylene is well suited for shipping covers and similar applications.	Y
6.4.5	High-density polyethylene is subject to stress cracking in the fuel blend. Of the polyethylenes, low density polyethylene is the most resistant. Irradiated and high-density polyethylene are limited in use because of shrinkage.	B
6.4.6	Kel-F 300 showed a stress cracking tendency due to exposure to Aerozine 50 after 70 days at 70° to 80°F, and became brittle within 30 days at 160°F. Mylar dissolved in Aerozine 50 at 55° to 60°F after 30 days exposure.	B

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6.4.7 The following materials are suitable for use as seals, gaskets, and O-rings in Aerozine 50 service: (Total immersion, continuous, or intermittent service)

Reference

Y

Application

Dynamic or Static extended service:
(Materials show no significant
change in excess of 90 days)

Materials

Fluorocarbon:
Teflon 100
Teflon 1
Polypropylene:
Pro-Fax
Polyethylene:
Marlex 50
Vinylidene Fluoride:
Kynar
Butyl Elastomers:
823-70
9257 and 9357
B480-7

Short-Term Dynamic or Static service: Nylon:
(60 days at $75 \pm 5^{\circ}\text{F}$ or 48 hrs. at
 $160 \pm 5^{\circ}\text{F}$)
Zytel 101
Zytel 31

6.4.8 The following lubricants and sealants are satisfactory for Aerozine 50 exposure:

Y

Polyglycol Oils

15-200
P-250
E-300
P-400
P-750
P-1200

Dow Chemical Co.

Silicone Oils

F-60
510
550

Dow Corning Corp.

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ReferenceSilicone Greases

Valve Seal A
High Vacuum
DC 11
XC 150

Dow Corning Corp.

Flake GraphiteProprietary

Apiezon-L
Reddy Lube 100
Reddy Lube 200
Glycolwax S-932

6.4.9 The following adhesives, coatings, and tapes are satisfactory for splash or brief, intermittent exposure with Aerozine 50:

Y

Adhesives and Coatings (No visible change after 24 hour immersion at $75 \pm 5^{\circ}\text{F}$)

Chloroprene

Neoprene N-250

Epoxy

EC-1469 and EC-1470
EC-1595
EC-1596
EC-1630
Epoxy Cement and Filler (W. J. Ruscoe Co.)
Epon 4-184
Epon 5-100-1
Epon 8-31
Epon 929
Epon VIII W/A

Modified Epoxy

Epon 422
Epon YP-100
Epon 1031 w/ BF_3 - 400

Reference

Phenolic
37-9X

Inorganic
Sauereisen P-1
Sauereisen P-7

Silicone
Q-3-0121
QZ-8-0903

Coatings (No visible change after 24 hour immersion at
75 ± 5°F)

Phenolic-Epoxy-Silicone
PT-201G

Silicone
DC-936
DC-994

Proprietary
Preferred Pyrochrome
DA-9

Fluorocarbon
Teflon w/steel Primer

Nylon
Zytel 31
Zytel 63
Zytel 101

Polyethylene
Marlex-50

Polypropylene
Pro-Fax

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Reference

**Tapes (NVC* after 24 hours immersion at 75 ± 5°F,
except as noted)**

Aluminum Backed

**Y 9040
7402-96272
759181-PP785
425 (NVC after 1/2 hr.)**

Polyethylene Backed

480 (NVC after 4 hr., adhesive failure after 24 hours)

Teflon Backed

**X1111
549 (NVC after 1 1/2 hr.)
7503 (NVC after 1/2 hr.)
SL 28011, Lot 306**

6.4.10 The following insulation materials are satisfactory for splash or brief intermittent propellant exposure with Aerozine 50:

YApplicationMaterial

**Thermal and Electrical for over
1000°F**

Inorganics:

**Sauereisen No. 7 Paste
Sauereisen No. 29
Sauereisen P-1
Sauereisen No. 6**

**Thermal and Electrical for 500°F
and up**

Fluorocarbon:

**Teflons
Phenolic
SC1008
F-120-55**

Epoxy

**Epon 1031/BF₃
Silicone**

**936 Electrical Varnish
994 Electrical Varnish**

**Thermal and Electrical under
500°F**

**Materials listed in para.
6.4.7**

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*No visible change

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SECTION 7 - ALCOHOLS

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		<u>Reference</u>
7.0	ALCOHOLS	
7.1	The materials considered here are Methyl Alcohol (METHANOL, CARBINOL, or WOOD Alcohol) and Isopropyl Alcohol (ISOPROPANOL) of 99.9% minimum purity, Ethyl Alcohol (ETHANOL or Grain Alcohol) per MIL-A-6091, and commercial grade Furfuryl Alcohol.	
7.2	Nature	
7.2.1	The alcohols are flammable liquids and will react vigorously with strong mineral acids or strong organic acids.	C
7.2.2	METHYL and ETHYL Alcohol will support combustion, once initiated, even though diluted to less than 50 percent concentration in water.	C
7.2.3	Alcohols shall not, under any circumstances, be stored with mineral acids, strong organic acids, or oxidizing materials such as chlorates, perchlorates, bromates, peroxides, and permanganates.	C, E
7.2.4	The alkyl alcohols are not hypergolic with nonfluorinated oxidizers; Furfuryl alcohol, however, is hypergolic with fuming nitric acid.	C
7.2.5	Closed vessels of Furfuryl alcohol at temperatures between 162.5°F and 251.6°F are explosive.	E
7.2.6	The alcohols can form explosive mixtures with oxidizers, and these mixtures can be exploded by impact, heat, or electric spark.	C
7.2.7	The liquid alcohols are not sensitive to mechanical shock.	C
7.3	Metals Compatibility	
7.3.1	Steel is the most commonly used material for the construction of drums, main storage tanks, and permanent storage facilities. Stainless steel and aluminum may be used.	C

USE FOR TYPED/PRINTED MATERIAL ONLY

	<u>Reference</u>
7.3.2 Methanol is quite corrosive to lead at ordinary temperatures. Aluminum not protected by an oxide film is slowly attacked.	E
7.3.3 Methyl alcohol will dissolve magnesium and its alloys.	C
7.3.4 Do not use methanol or chloride containing solutions with titanium and zirconium alloys, due to reported chloride stress corrosion cracking of these alloys.	D
7.4 Nonmetals Compatibility	
7.4.1 The materials listed below are acceptable for fabrication of items coming in contact with alcohols.	C
Polyvinyl Chloride Neoprene] Rubber Except for Furfuryl Alcohol Kel-F Teflon Polyethylene Asbestos Gasket Material	
7.4.2 Specialized lubricants, such as fluorinated hydrocarbons, molybdenum disulfide, and graphite-based lubricants, must be used wherever the alcohol can come in contact with the lubricant.	C
7.4.3 Petroleum lubricants must not be used in contact with alcohol.	C
7.4.4 The following sealing compounds may be used in alcohol systems:	C
Gasolia Cement Permatex No. 2 Litharge and Glycerin	

SECTION 8 - ALKYL BORANES

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		Reference
8.0	ALKYL BORANES	
8.1	NOTE: This is provisional information. Owing to the lack of experience in handling these propellants, it is incomplete. Users are cautioned against extrapolating the information contained here. More detailed information is available in classified documents.	
8.1.1	The materials considered here are the alkyl borane fuels, HiCal-3, HEF-2, and HEF-3.	
8.2	Nature	
8.2.1	The alkyl boranes may react violently with oxidizing materials and the hydrazines.	C
8.2.2	With halogenated hydrocarbons, they may react or form explosive mixtures.	C
	<u>WARNING</u>	
	Carbon dioxide and halogenated vaporizing liquids (e.g., carbon tetrachloride) must not be used to fight any alkyl-borane fire. Water fog or inert-gas foam are acceptable extinguishing agents.	
8.2.3	HEF-2 may ignite spontaneously in air.	C
8.2.4	HiCal-3 and HEF-3 are soluble in, but react with, alcohols. HEF-2 reacts violently with alcohols.	C
8.2.5	Vapors from these fuels are highly toxic and can cause damage to the eyes, lungs, and upper respiratory tract, as well as systemic effects.	C
8.3	Metals Compatibility	
8.3.1	Alkyl borane fuels are not corrosive to most metals; therefore, storage and transfer systems may be constructed of nearly all common metallic materials.	C

USE FOR TYPEWRITTEN MATERIAL ONLY

Reference

8.3.2 Listed below are some metals which are considered satisfactory for this service:

Iron	Incoloy	Monel
Steel	Stainless Steel	Nionel
Nickel	Inconel	Aluminum

8.4 Nonmetal Compatibility

8.4.1 Alkyl Boranes are corrosive to most rubbers and plastics.

8.4.2 The use of non-metallic materials should be limited to those specified in para. 8.4.3 below, unless properly tested and approved for this service.

8.4.3 Some materials found to be acceptable for use are as follows:

With HiCal-3 and HEF-3: Teflon
 Kel-F
 Johns-Manville Gasket Material No. 76
 Quigley Co. - Q-Seal Thread Compound
 General Electric Co. - Glyptal Thread
 Compound
 Graphited Asbestos
 Kel-300
 Nylon

With HEF-2: Teflon
 Kel-F

8.4.4 The following materials have been found satisfactory for repeated short term service only with HiCal-3:

Bakelite
 Epoxy Resin
 Fluoro Rubber
 Fluorosilicone Rubber
 Polyvinyl chloride pipe (EASTON)
 Teflon Asbestos packing (above 120°F)

USE FOR TYPEWRITTEN MATERIAL ONLY

	<u>Reference</u>
8.4.5 The following materials are <u>not recommended</u> for use with HiCal-3 and HEF-3:	X
Fairprene 5051 and 5039	
Garlock binders, No.'s 900, 7021, 7228, 7705, and 8748	
Neoprene	
Plexiglas	
Polyethylene tubing	
Natural rubber	
Silicone rubber	
Tyrgon tubing	
8.4.6 Graphite is the <u>only known lubricant</u> that can safely be recommended.	C

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SECTION 9 - ANHYDROUS AMMONIA

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		<u>Reference</u>
9.0	ANHYDROUS AMMONIA	
9.1	The material considered here is propellant grade Anhydrous Ammonia conforming to MIL-P-27406, 9 May 1966.	
9.2	Nature	
9.2.1	Ammonia is reactive, alkaline in nature, and is a reducing agent.	C
9.2.2	Vapor concentrations of 16 to 27 percent by volume burn in air.	C
9.2.3	Contact of ammonia with certain other chemicals, including mercury, chlorine, iodine, bromine, calcium, silver oxide, and hypochlorite, can form explosive compounds.	C
9.2.4	Ammonia is very stable and is not shock sensitive. It is thermally stable at temperatures as high as 900°F, above which dissociation to nitrogen and hydrogen begins.	C
9.3	Metals Compatibility	
9.3.1	Moist ammonia will not corrode iron, steel, or aluminum, but will react rapidly with copper, brass, zinc, and many alloys, especially those containing copper.	C
9.3.2	Steel is the preferred material for ammonia containers, fittings, and piping, except that fabricated equipment made of certain nonferrous alloys may be used.	C
9.3.3	The following materials are approved for ammonia service:	C
a.	<u>Ammonia, Anhydrous (liquid)</u> Nickel (all temperatures) Stainless Steel, 300 and 400 series (all temperatures) Steel (ambient temperature)	
b.	<u>Ammonia (vapor)</u> Nickel Steel (ambient temperature) Stainless Steel, 300 and 400 series	

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	<u>Reference</u>
9.3.4 Gold, even in minute amounts, can cause fuel decomposition when used in contact with ammonia or ammonia-based fuels.	H
9.4 Nonmetal Compatibility	
9.4.1 The following list are some materials approved for ammonia service:	C
Teflon	
Kel-F	
Pure Asbestos (free of grease and graphite)	
9.4.2 Other materials may be used which have been properly tested and approved for ammonia service.	C
9.4.3 The materials listed below are not recommended for ammonia service:	H
Silicone Resins	
Vinylidene chloride	
Thiokol Rubber	
9.4.4 Ammonia will react with organic or inorganic acids to form salts.	C
9.4.5 Refrigeration-grade petroleum oil may be used for pumps and compressors.	C
9.4.6 Specialized lubricants, such as the fluorolubes or the perfluorocarbons, are required in missile systems where contact with oxidizers is a possibility, except that they <u>shall not</u> be used with aluminum.	C
9.4.7 Silicone greases may be used.	C
9.4.8 Silicone Resin Sealants are not recommended for any use with ammonia systems.	H

SECTION 10 - ANILINE

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	<u>Reference</u>
10.0 ANILINE (Aniline oil, aminobenzene)	
10.1 The material considered here is Aniline conforming to Military Specification MIL-A-10450.	
10.2 Nature	
10.2.1 Aniline is mildly alkaline and reacts with moderately concentrated strong mineral acids.	C
10.2.2 Aniline is hypergolic with fuming nitric acids.	C.
10.2.3 Aniline is a flammable liquid with an autoignition temperature of approximately 1400°F.	E
10.2.4 Aniline may be regarded as somewhat less flammable than kerosene and subject to the same handling precautions.	E
10.2.5 Mixtures of aniline and air are not explosive, but are flammable.	E
10.2.6 Aniline is considered non-corrosive, but slowly attacks non-ferrous metals and some organic materials.	C
10.2.7 Aniline is highly toxic when absorbed through the skin, inhaled as a vapor, or swallowed.	C, E
10.3 Metals Compatibility	
10.3.1 Aniline is not considered corrosive to either ferrous or non-ferrous metals, although the latter are slowly attacked.	C
10.3.2 Storage tanks, associated piping and fittings, pumping equipment, valves, etc., should be fabricated from mild steel.	C
10.4 Nonmetals Compatibility	
10.4.1 Listed are some of the nonmetals recommended for use in fabrication:	C
Fiberglass Koro-seal Vinylite	Teflon Rubber (butyl only) Commercial-Type Asbestos

	<u>Reference</u>
10.4.2 Conventional petroleum lubricants are <u>not recommended</u> .	C
10.4.3 Perhalogenated hydrocarbon oils, graphite-based lubricants, and molybdenum disulphide may be used.	C

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SECTION 11 - CHLORINE TRIFLUORIDE

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Reference

11.0	CHLORINE TRIFLUORIDE (CTF)	
11.1	Chlorine Trifluoride, ClF_3 , considered here is of 99% minimum purity.	
11.2	Nature	
11.2.1	CTF is a toxic and corrosive oxidizing agent, similar to elemental fluorine in reactivity.	C
11.2.2	CTF is hypergolic and reacts vigorously with water and most combustible substances at room temperature, frequently igniting immediately.	C
11.2.3	CTF reacts with most metals and metal oxides at elevated temperatures.	C
11.2.4	It reacts strongly with silicon-containing compounds, and, thus, can support the continued combustion of glass, sand, asbestos, etc.	C
11.2.5	CTF is especially reactive with moisture.	C
11.2.6	A mixture with carbon tetrachloride can be detonated.	C
11.3	Metals Compatibility	
11.3.1	Such metals as copper, silver-solder, brass, steel, magnesium, aluminum, monel, or nickel are satisfactory for use with CTF.	C
11.3.2	The preferred metals are: Monel 18-8 Stainless Steel Nickel	C
11.3.3	Gaskets for CTF service may be made from soft copper, 2S aluminum, or Teflon laminated with copper or another metal, provided that no point on the exposed Teflon surface is more than 0.002 to 0.003 inch removed from a metal heat conductor.	C
11.4	Nonmetal Compatibility	

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<u>Reference</u>			
11.4.1	Approved nonmetals are as listed below:		C
	Neoprene - protective clothing only		
	Kel-F - not recommended for flow conditions		
	Teflon - not recommended for flow conditions		
	Pyrex glass		
11.4.2	The following materials are prohibited for use with Chlorine Trifluoride:		X
	Carbon with plastic binders		
	Epoxy-filled carbon (KARATE #15 and 25)		
	Graphite with plastic binders		
	Fluorel		
	Fluorosilicone		
	Hydropol		
	Kel-F 5500		
	Nylon		
	Polyethylene		
	Rubber (all common types)		
<u>CAUTION</u>			
	Vinyl-coated materials react violently with CTF and shall not be used.		C
11.4.3	Teflon impregnated with 40 percent calcium fluoride is an acceptable gasket material.		V
11.4.4	The use of the standard petroleum-based lubricants is prohibited. Fluorinated hydrocarbons may react violently with CTF.		C
11.4.5	No completely satisfactory lubricant is known.		C
11.4.6	The following are additional Polymers recommended for service with CTF:		S
Condition	Polymer	Tested Immersion Time (days)	Temperature
Static	Nitroso copolymer gum	5	Ambient room temp.
Static	Teflon TFE	30	158°F
Static	Teflon FEP	30	158°F
Static	Kel-F 81	30	Ambient room temp.

SECTION 12 - ETHYLENE OXIDE

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	<u>Reference</u>	
12.0	ETHYLENE OXIDE (1, 2 - Epoxyethane, Oxirane)	
12.1	The Ethylene Oxide considered here is essentially 100 percent C_2H_4O .	
12.2	Nature	
12.2.1	The vapor of ethylene oxide is flammable in air in all proportions above 3 percent by volume.	C
12.2.2	Ethylene oxide can polymerize in the presence of such materials as pure anhydrous chlorides of iron, tin, and aluminum, oxides of iron, aluminum, and magnesium, the alkali metal hydroxides and acids - often with violence and always with the liberation of heat.	C
12.2.3	Since acetylene may be a trace impurity in diluent gases used in connection with ethylene oxide, acetylide-forming metals such as copper, silver, mercury (including mercury-filled thermometers), and magnesium and its alloys must not be used in equipment to handle this propellant.	E
12.2.4	Ethylene oxide may also react with other materials and thereby create enough heat to accelerate polymerization of unreacted oxides. It will react exothermally with such compounds as the alcohols, amines, ammonias, and organic or mineral acids.	E
12.2.5	Liquid ethylene oxide itself is not sensitive to mechanical shock, but the vapor explodes when exposed to an electric spark, static electricity, excessive heat, open flame, or detonating agents.	C
12.3	Metals Compatibility	
12.3.1	Containers for the storage and transfer of ethylene oxide shall be constructed of any of the following acceptable materials: Mild Steel - property protected from corrosive atmospheres to prevent the formation of rust Stainless Steel Pure Aluminum (99.6 percent, or better)	C

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Reference

12.3.2 The following metals must not be used with ethylene oxide: C

Copper and Copper Alloys
Silver and Silver Alloys
Magnesium and Magnesium Alloys
Steel or Iron containing any trace of rust

12.4 Nonmetal Compatibility

12.4.1 Approved nonmetals are as follows: C

a. For temperatures up to 160°F:

Teflon
Kel-F
Glass

b. Ambient temperature only, for short durations or intermittent use:

Polyvinyl butyral
Nylon
Buna-N synthetic rubber

12.4.2 Only fluorinated hydrocarbon lubricants shall be used for ethylene oxide equipment. Petroleum-based lubricants are prohibited. C

SECTION 13 - FLUORINE

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USE FOR TYPED MATERIAL ONLY

		<u>Reference</u>
13.0	FLUORINE	
13.1	Considered here is propellant grade fluorine, essentially 100 percent pure F ₂ , containing only traces of oxygen, nitrogen, and hydrogen fluoride.	
13.2	Nature	
13.2.1	Fluorine is the strongest oxidizing agent and one of the most reactive materials known and will react with practically all organic and inorganic substances. The few exceptions are the inert gases and metal fluorides.	C
13.2.2	Fluorine reacts with all metals under conditions of elevated temperature and pressure. However, the formation of impermeable fluoride coatings on some metals produces satisfactory materials for construction of containers for fluorine.	E
13.2.3	Containers of fluorine must not be subjected to shock or heat, as a violent reaction with the container is possible. Unconfined fluorine is stable to shock, heat, and electrical spark.	C
13.2.4	Fluorine reacts violently with water, solvents, and acids. It is hypergolic with water vapor, ammonia, hydrogen, most fuels, and organic vapors.	E
<u>NOTE</u>		
	Water, in the form of moisture in the atmosphere or contained in pressurant or purge gases which were inadvertently introduced into a fluorine system, has been a major cause of fluorine system failures.	U
13.2.5	Fluorine is completely miscible with liquid oxygen and liquid nitrogen.	C
13.2.6	The reaction characteristics of the fluorine-oxygen (FLOX) mixtures are similar to those of fluorine, except that, at lower concentrations, FLOX mixtures tend to become less hypergolic as the percent fluorine in the mixture is decreased. In fluorine concentrations as low as 5 to 10 percent, FLOX ignites spontaneously with many materials and must be considered in the same manner as propellant grade fluorine.	U

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	<u>Reference</u>
13.2.7 All liquid-fluorine storage tanks must be jacketed with liquid nitrogen to maintain the fluorine at a temperature below its boiling point.	C
13.3 Metals Compatibility	
13.3.1 The selection of suitable fabricating materials for a liquid fluorine system must be governed by two important factors:	C
a. The resistance of the material to fluorine attack.	
b. The material mechanical strength at cryogenic temperature.	
13.3.2 In general, metals with low corrosive rates at atmospheric conditions and with high kindling temperatures are resistant to fluorine.	C
13.3.3 With fluorine, the key to using compatible materials has not been so much the choice of metals as the cleanliness. Most erratic behavior and ignition of metals has resulted from contamination.	G
13.3.4 The following metals are recommended for use with pressurized gaseous fluorine:	C
Nickel	
Monel	
Copper	
13.3.5 Although stainless steel is sometimes used with pressurized gaseous fluorine, its use should be avoided because its corrosion tends to be localized rather than uniform, adherent, and smooth as in nickel, monel, and to a certain extent in copper.	O
13.3.6 Metals considered satisfactory for handling gaseous fluorine at room temperatures are as follows:	C
Nickel	Brass
Monel	Copper
Steel	Aluminum
Stainless Steel	Magnesium

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		Reference
13.3.7	For liquid fluorine, the following metals are recommended:	C
	Monel	
	Aluminum	
	Stainless Steel, Types 304L, 321, and 347 (Type 347, however, is crack-sensitive)	
	Copper	
	Brass	
13.3.8	The following metals must not be used in liquid fluorine service:	G
	Low-carbon Steel	
	Cast Iron	
	Cast Monel	
	Lead	
	Molybdenum	
	Tantalum	
	Titanium	
	Columbian	
	Zirconium	
13.3.9	The following materials selection criteria have been established for equipment used with fluorine and fluorine containing oxidizers:	G
a.	Choose materials on the basis of the best possible compatibility with the oxidizer, consistent with the function of the part.	
b.	Require testing of the material with the oxidizer before using it in a component if there is doubt about compatibility.	
c.	Avoid the use of platings and coatings on metals wherever possible. (See 13.3.10)	
d.	Avoid the use of nonmetallic materials in areas exposed to oxidizer flow. If Teflon (TFE) is used as a static seal for the storable oxidizers, use it in small section, closely surrounded by metal, and with minimum surface area exposed. Teflon (TFE) may also be used for a secondary seal if the cavity between the primary and secondary seals is either vacuum scavenged or inert gas purged.	
e.	Do not use lubricants or pipe compounds on joints in the fluid system.	

Reference

- f. Do not use soft or stringy valve stem packings requiring periodic replacement; they are gradually deposited in the fluid stream.
- g. Investigate before using two different metals in direct contact with each other to determine whether they are compatible from the galvanic corrosion standpoint.
- h. Use nonporous castings (if castings are necessary), free of sand and other foreign materials. Porous castings (particularly aluminum and bronze) should not be used because they are difficult to clean. All castings should be X-rayed. Dye penetrant inspection shall not be used.
- i. Non-magnetic metals shall be used for all metallic parts of quick disconnect couplings, except where magnetic metals are essential.

13.3.10 Spray-coated or calcined aluminum oxide is resistant to gaseous and liquid fluorine under flow conditions at low as well as high temperatures. C

13.4 Nonmetal Compatibility

13.4.1 The following materials are acceptable for use, at moderate pressures and low flow rates, with gaseous fluorine: C

Teflon TFE
Kel-F
Halon

13.4.2 Vinyl-coated materials react violently with fluorine and must not be used. C

13.4.3 There are no plastics acceptable for use with liquid fluorine under flow conditions. C

13.4.4 Fluorine reacts with organic, aqueous, or silicone materials otherwise considered inert and with all oxidizable materials. Silicones and standard petroleum-based lubricants, therefore, are not usable. C

13.4.5 There are no reliable lubricants for fluorine service. C

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13.4.6	Certain other nonmetallic materials, such as synthetic sapphire, Norbide, and Kentanium, reportedly react very slowly in fluorine and may be suitable for certain applications.	G
13.4.7	In general, the highly fluorinated and highly chlorinated materials are more suitable for use in fluorine systems than materials containing atoms such as hydrogen in their molecular structures or materials impregnated with some noncompatible additive.	U
13.5	Materials Table The following materials have been satisfactorily used for fluorine system components.	V

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<u>COMPONENT</u>	<u>GASEOUS SERVICE</u>	<u>LIQUID SERVICE</u>
Storage Tanks -----	Stainless Steel (304L, 347) Aluminum 61 Mild Steel (low pressure)	Monel Stainless Steel (304L, 347) Aluminum 61
Lines, fittings, ----- and flanges	Stainless Steel (300 series) Aluminum Copper Brass Mild Steel (low pressure)	Monel Stainless Steel (300 series) Aluminum 60 Inconel Copper (low pressure)
Valve Bodies -----	Nickel Monel Stainless Steel (300 series) Inconel Brass Bronze	Nickel Monel Stainless Steel (300 series)
Valve Seats -----	Nickel Copper Brass Aluminum	Nickel Copper Brass Aluminum
Valve Plugs -----	Monel Stainless Steel (300 series)	Monel Stainless Steel (300 series)
Seals:		
Gaskets-----	Soft Aluminum Soft Copper Teflon Kel-F	Soft Copper Soft Aluminum
O-ring-----	Aluminum Teflon	Copper Aluminum Stainless Steel (hollow-pressurized)
Chevron Packing-----	Kel-F	
Washer Packing-----	Lead	

SECTION 15 - HYDROCARBON FUELS

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Reference

14.0	HYDRAZINE	
14.1	Propellant-grade hydrazine contains a minimum of 97 percent hydrazine, N_2H_4 , the remainder being primarily water. Military Specification MIL-P-26536 (USAF), 13 March 1964, covers the grade discussed herein.	
14.2	Nature	
14.2.1	Hydrazine reacts with air, metal oxides, and oxidizing agents and absorbs water readily. Consequently, hydrazine transfer and storage systems must be free of air, moisture, rust, and contamination.	L
14.2.2	Hydrazine is considered a hazardous propellant due to its toxicity, reactivity, and flammability.	L
14.2.3	Hydrazine decomposes on contact with some metals, including iron, copper, molybdenum, and their alloys and oxides.	C
14.2.4	Hydrazine vapor is flammable in all concentrations in air above 4.7 percent.	C
14.2.5	Hydrazine is hypergolic with nitric acid, concentrated hydrogen peroxide, nitrogen tetroxide, chlorine trifluoride, and other reactive oxidizers at atmospheric pressures.	K
14.2.6	Liquid hydrazine is not sensitive to shock or friction.	C
14.2.7	During handling and storage, liquid hydrazine must be maintained under an inert atmosphere (usually a gaseous nitrogen blanket) which reduces its flammability and reactive potential in air.	K
14.2.8	Liquid hydrazine at temperatures of 104°F and above exerts sufficient vapor pressure to form flammable air mixtures.	L
14.2.9	Hydrazine is a highly polar electrolytic solvent. It is soluble in water, methanol, unsymmetrical dimethylhydrazine (UDMH), and ethylenediamine, but is insoluble in ethers and hydrocarbons.	L
14.3	Metals Compatibility	

	<u>Reference</u>
14.3.1 When properly cleaned and prepared, the following metals can be successfully used in hydrazine systems:	C, L, AG
Stainless Steel 303, 304, 321, and 347	
Stainless Steel 316 (limited to 160°F)	
Aluminum 1060, 1100, 2014-T6, 3003, 5052, 5154, and 6061	
Inconel (70°F)	
Inconel-X	
Chromium Plating	
Stellite 21	
Titanium 6Al-4V	
14.3.2 In general the prohibited materials are:	C, L
Nickel (above 130°F)	
Hastelloys	
Monel (above 130°F)	
Aluminum 40-E (sand casting)	
Magnesium	
Zinc	
Lead	
Brass	
Copper (see para. 14.3.5)	
Silver	
Cadmium plating	
Iron	
Manganese	
14.3.3 Alloys containing over 0.5 percent of molybdenum must not be used at temperatures above 160°F.	L, V
14.3.4 Hydrazine is a strong reducing agent which reacts violently with oxides of iron and copper, particularly at elevated temperatures. Hydrazine forms explosive compounds (azides) with silver and mercury. Molybdenum oxide is extremely catalytic to Hydrazine.	L
14.3.5 Copper and nickel are satisfactory for limited service and may be used if free of oxides and at temperatures of 100°F or less. These materials are not recommended for use other than propellant transfer or similar use.	L
14.3.6 Carbon steels are to be avoided, especially with the fuel blends.	V

USE FOR TYPEWRITTEN MATERIAL ONLY

	<u>Reference</u>
14.3.7 For long term storage at elevated temperatures, containers of Aluminum Alloy 1100-0 are recommended. (This material tested under accelerated storage conditions: 4 weeks at +100°F and 48 weeks at +165°F.)	AD
14.4 Nonmetal Compatibility	
14.4.1 The following materials are approved for hydrazine service:	C, L, X
Teflon	
Kel-F (unplasticized)	
Graphite	
High-density polyethylene	
Dow Corning No. 11	
Sinclair L743 (MIL-L-25336)	
Butyl rubber, compound 805-70	
Fluorobestos	
Garlock 735	
Polybutadiene (Cis-1, 4)	
14.4.2 Gaskets may be of Teflon, polyethylene and type 304 stainless steel, spiral-wound (Flexitallic, Spirotallic or equivalent).	C
14.4.3 For valve stems, solid Teflon cylinders, chevron V-rings, or braided Teflon equivalent to John Crane 704 or Garlock 5733 may be used.	C
14.4.4 Thus far, a completely satisfactory lubricant has not been developed. The Quigley Company's "Q-Seal" is being used with fair results.	C
14.4.5 A new fluorinated grease by DuPont, Krytox 240, has been found compatible with hydrazine and used with fair results.	(TRW Report)

USE FOR TYPEWRITTEN MATERIAL ONLY

		<u>Reference</u>
15.0	HYDROCARBON FUELS (JP and RP FUELS)	
15.1	The hydrocarbon fuels contained herein conform to the applicable specification listed below:	
	MIL-G-3056, "Gasoline, Automotive, Combat"	
	MIL-F-5572A, "Gasoline, Aviation, Grades 80/87, 91/96, 100/130, 115/145"	
	MIL-G-5624B, "Fuel, Aircraft Turbine and Jet Engine, Grades JP-3, JP-4, JP-5"	
	MIL-F-19605 (Ships), "Fuel, Ballistic Missile (Ships)"	
	MIL-F-25524 (USAF), "Fuel, Aircraft Turbine and Jet Engine, Thermally Stable"	
	MIL-F-25558 (USAF), "Fuel, Ramjet Engine"	
	MIL-R-25576B, "Fuel, Rocket Engine, Grade RP-1"	
	MIL-F-25656 (USAF), "Fuel, Aircraft Turbine and Jet Engine, Grade JP-6"	
	MIL-T-38219 (USAF), (Proposed), "Turbine Fuel, Low Volatility"	
15.2	Nature	
15.2.1	Hydrocarbon fuels react only under the strongest oxidizing conditions or at extremes of pressure and temperature.	C
15.2.2	These fuels are chemically stable and insensitive to shock.	C
15.2.3	Hydrocarbon fuel vapors readily form mixtures with air that can be exploded by electric sparks, static electricity, and similar energy sources.	C
15.2.4	If hydrocarbon fuels and rocket oxidizers are spilled and allowed to mix, the resultant mixture can be exploded by mechanical shock, heat, or spark; it will even explode spontaneously. This hazard exists with respect to high vapor concentrations of the fuel and oxidizer, as well as the liquid mixtures.	C

USE FOR TYPEWRITTEN MATERIAL ONLY

Reference

15.0 HYDROCARBON FUELS (JP and RP FUELS)

15.1 The hydrocarbon fuels contained herein conform to the applicable specification listed below:

MIL-G-3056, "Gasoline, Automotive, Combat"

MIL-F-5572A, "Gasoline, Aviation, Grades 80/87, 91/96, 100/130, 115/145"

MIL-G-5624B, "Fuel, Aircraft Turbine and Jet Engine, Grades JP-3, JP-4, JP-5"

MIL-F-19605 (Ships), "Fuel, Ballistic Missile (Ships)"

MIL-F-25524 (USAF), "Fuel, Aircraft Turbine and Jet Engine, Thermally Stable"

MIL-F-25558 (USAF), "Fuel, Ramjet Engine"

MIL-R-25576B, "Fuel, Rocket Engine, Grade RP-1"

MIL-F-25656 (USAF), "Fuel, Aircraft Turbine and Jet Engine, Grade JP-6"

MIL-T-38219 (USAF), (Proposed), "Turbine Fuel, Low Volatility"

15.2 Nature

15.2.1 Hydrocarbon fuels react only under the strongest oxidizing conditions or at extremes of pressure and temperature. C

15.2.2 These fuels are chemically stable and insensitive to shock. C

15.2.3 Hydrocarbon fuel vapors readily form mixtures with air that can be exploded by electric sparks, static electricity, and similar energy sources. C

15.2.4 If hydrocarbon fuels and rocket oxidizers are spilled and allowed to mix, the resultant mixture can be exploded by mechanical shock, heat, or spark; it will even explode spontaneously. This hazard exists with respect to high vapor concentrations of the fuel and oxidizer, as well as the liquid mixtures. C

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15.2.5 The principal personal hazards involved in the handling of the hydrocarbon fuels are: C

- a. Prolonged exposure of the body
- b. Inhalation of the vapor
- c. Fire

15.3 Metals Compatibility

15.3.1 Storage tanks, associated piping and fittings, pumping equipment, valves, and all other metal parts should be fabricated from steel. C

15.3.2 A protective external coating must be applied to all ferrous metals in contact with atmospheric moisture. C

15.3.3 Copper alloys (with zinc, tin, or beryllium) shall not be used where they will be continually in contact with fuel, as they promote gum formation. C

15.3.4 Galvanized metal (or zinc) shall not be used with leaded fuels. C

15.3.5 The materials listed below were tested for compatibility with the test fuel conforming to the proposed MIL-T-38219 (USAF), unofficially termed "JP-7."* A

- a. The following materials are approved for use:

Low Carbon Steel
Stainless Steel
Aluminum Alloy 5052-H32
Aluminum Alloy 6061-T6
"M" (furan) and "N" (epoxy) coated Steel (MIL-C-4556B)
Filter-separator elements (MIL-F-52308)

- b. The following materials were found to degrade fuel thermal stability significantly during long-term storage:

Brass
Bronze
Water or Rusty Steel
Copper or Zinc

*This fuel is a thermally stable, low volatility, naphthenic type jet fuel.

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Reference**15.4 Nonmetal Compatibility**

15.4.1 Listed below are some of the recommended nonmetals approved for this service: C

Vinyls
Fluorocarbons (Teflon and Kel-F)
Polyethylene
Polyamides
Neoprene
Buna N
Asbestos, cork, and paper gasket material
Plug valve grease (MIL-G-6032B, Type I)

15.4.2 The following are nonmetallic materials prohibited for use with the hydrocarbon fuels: C

Polyisobutylenes (Vistanex)
Acrylics
Natural rubber and synthetics other than those listed as usable

15.4.3 Since hydrocarbon fuels are excellent solvents for most organic matter, petroleum lubricants cannot be used in contact with these fuels. C

15.4.4 Graphite-base, molybdenum-disulfide, and some silicone and fluorocarbon lubricants may be used. C

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SECTION 16 - HYDROGEN PEROXIDE

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Reference**16.0 HYDROGEN PEROXIDE**

16.1 The propellant considered here conforms to MIL-P-16005E, 31 Jan 1968. Hydrogen Peroxide covered by this specification is of the following types: (percent by weight)

Type I - 91.0 max to 90.0 min

Type II - 99.0 max to 98.0 min

For this document, the characteristics of materials compatibility apply to both types, except where noted.

16.2 Nature

16.2.1 Propellant-grade hydrogen peroxide is a monopropellant and an active oxidizing agent.

C

16.2.2 Hydrogen peroxide does not burn but vigorously supports combustion with the liberation of oxygen when decomposing.

C

16.2.3 Owing to its strong oxidizing nature, it can initiate the combustion of many organic materials - wood, cotton, waste, etc. Type II hydrogen peroxide reacts under certain conditions with many organic compounds, such as carbonyl compounds and phenolics.

C

16.2.4 Hydrogen peroxide is hypergolic with hydrazine.

C

16.2.5 It decomposes rapidly on contact with many inorganic compounds, such as potassium permanganate and ferrous sulfate.

C

16.2.6 When decomposed by catalysts, it generates heat rapidly.

C

16.2.7 Hydrogen peroxide is miscible with water and water-soluble organic liquids, such as alcohols, glycols, acetates, acids, and ketones.

C

16.2.8 It is insoluble in petroleum ether, toluene, styrene, carbon tetrachloride, chloroform, kerosene, fuel oil, and gasoline.

C

16.2.9 Many organic liquids, both soluble and insoluble, can form explosive mixtures with hydrogen peroxide. When organic solvents such as ketones, alcohols, and glycols are added to H_2O_2 , the resulting solutions become shock-sensitive.

C

Reference**16.3 Materials Classification**

16.3.1 A system of four classes has generally been adopted for materials for hydrogen peroxide service. The classes are arbitrary, but they do provide a standard for rating materials compatibility. These classes are:

C, F

Class 1: Materials Satisfactory for Unrestricted Use with H₂O₂. Such services include long-time contact with the H₂O₂. Typical use is for storage containers.

Class 2: Materials Satisfactory for Repeated Short-time Contact with H₂O₂. Such materials are used for transient contact with the H₂O₂ prior to storage, or limited contact with H₂O₂ prior to use. Such contact is not to exceed 4 hours at 160°F (72°C) or 1 week at 70°F (22°C). Typical uses are for valves and pumps in H₂O₂ transfer lines and feed tanks.

Class 3: Materials which should be used only for Short-time Contact with H₂O₂. These materials should be used where neither a Class 1 nor Class 2 material would suffice. These materials can be used for repeated contact, but a single use period should not exceed 1 minute at 160°F or 1 hour at 70°F. An example of a Class 3 application is materials for use in a flow system.

Class 4: Materials not Recommended for Use with H₂O₂. These materials (1) cause excessive decomposition of H₂O₂, even on short-time contact, (2) are attacked or deteriorate on contact, (3) yield corrosion or deterioration products which cause excessive decomposition of H₂O₂ on subsequent contact, or (4) form impact-sensitive mixtures with concentrated H₂O₂.

USE FOR TYPEWRITTEN MATERIAL ONLY

16.4	Metals Compatibility	<u>Reference</u>
16.4.1	In selecting materials for fabricating hydrogen-peroxide equipment, the effect of the peroxide on the material is of considerably less importance than the material's effect on the peroxide.	C
16.4.2	The chemical composition of a material is not the sole factor determining its compatibility. The liquid-phase decomposition of hydrogen peroxide is markedly affected by the nature of the surface exposed to the liquid. In general, the smoother the surface, the lower the decomposition rate of hydrogen peroxide.	C
16.4.3	The following is a listing of the material classifications for the various metals listed.	C

Pure Metals

Class 1 (long-time contact):

Aluminum (less than 0.5 percent Cu)
Tantalum
Zirconium

Class 2 (short-time contact before storage):

(Same as Class 1)

Class 3 (short-time contact before use):

Aluminum (less than 0.5 percent Cu)
Tantalum
Tin
Zirconium

Class 4 (not suitable):

Beryllium	Magnesium
Cadmium	Nickel
Chromium	Platinum
Cobalt	Silver
Copper	Titanium
Gold	Tungsten
Iron	Zinc
Lead	

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ReferenceAluminum Alloys**Class 1 (long-time contact):**

1060	5254
1260	5652
1360	B356*

Class 2 and 3 (short-time contact):

1060	5052	1505*
1100	5054	214B*
1260	5056	214F*
1360	5254	356*
3063	5652	B356*
4043	6061	
	6063	

Stainless Steel, Wrought Alloys, and Others**Class 1 (long-time contact):**

- None -

Class 2 (short-time contact before storage):

AISI 304	AISI 317
AISI 304 (ELC)	AISI 321
AISI 309	AISI 347
AISI 310	AISI 316 (ELC)
AISI 316	

Class 3 (short-time contact before use):

AISI 304	AISI 347
AISI 304 (ELC)	AISI 316 (ELC)
AISI 309	Durimet
AISI 310	Hastelloy B
AISI 316 (nonporous)	Hastelloy C
AISI 317	Hastelloy D
AISI 321	Worhite

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*Castings

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Reference**Class 4 (not suitable):**

AISI 316 (porous)	Monel
Stainless Steel	Stellite Nr. 6
400 series	Silver Solder
Inconel	

16.4.4 Various seamless stainless steel tubing can be used for high-pressure systems, but the 304 (ELC), 316 (ELC), 321, or 347 alloys should be used if welding is required. F

16.4.5 Stainless steel and aluminum components must not be coupled in the same system. F

16.4.6 Free-machining stainless steel alloys must not be used. F

16.4.7 Cast stainless steel components should not be used unless the particular casting is thoroughly proved to be suitably compatible with hydrogen peroxide. F

16.4.8 All markings must be removed from stainless steel plates before they are formed into a tank. F

16.4.9 Lap joints shall not be used in fabrication of materials. Lap joints provide cracks, crevices, etc. (which cannot be readily cleaned), and may furnish a source of contamination. F

16.4.10 Flux and carbon formed in fabrication must be cleaned from welded areas in stainless steel by a 300 series stainless steel wire brush. Any inclusions remaining must be ground out. F

16.4.11 For the grinding of cast surfaces, welds, and weld spatter on surfaces that will contact propellant-grade hydrogen peroxide, a clean white aloxide (aluminum oxide) abrasive is recommended. F

16.4.12 Carborundum is not recommended for grinding because the iron in the carborundum is catalytic with H_2O_2 . F

16.4.13 Metallizing or sprayed metal coatings are not suitable techniques for preparing surfaces for H_2O_2 service. F

16.4.14 Sandblasting is not recommended because it reduces the compatibility of metals with H_2O_2 due to the formation of a porous or pitted surface. F

USE FOR TYPEWRITTEN MATERIAL ONLY

	<u>Reference</u>
16.4.15 Mechanical polishing of aluminum alloys is not advisable because of the possibility of introducing materials which are not compatible. Electrochemical polishing (anodization) of aluminum is the recommended method.	F
16.4.16 If an aluminum system is employed, it should be anodized per MIL-A-8625 (with no dyes), followed by a 1-hour rinse in boiling distilled water.	F
16.4.17 Hydrogen peroxide system components must not be brazed or silver soldered.	F
16.4.18 Chromic acid solutions shall not be used for cleaning.	F
16.5 Nonmetal Compatibility	
16.5.1 The following is a listing of the material classifications for various nonmetals.	C, F

Nonmetals (excluding lubricants)

Class 1 (long-time contact):

Teflon
Kel-F
Aclar

Class 2 (short-time contact before storage):

Teflon	Tygon 3604 A and B
Kel-F	Vitron A and B
Koro seal No. 700	
Polystyrene	
Silicone rubber Nos.	
SE 450, 59711, 56128, Y1749	

Class 3 (short-time contact before use):

Teflon	Tygon 3604 A and B
Kel-F	Vinylite
Koro seal No. 700	Vitron A and B
Polystyrene	
Silicone rubber Nos.	
SE 450, 59711, 56128, Y1749	

ReferenceNonmetals (excluding lubricants)**Class 4 (not suitable):**

Buna S	Neoprene
Buna N	Nylon
Geon 8372	Thiokol rubber
Hycar	Tygon 2807

Lubricants**Class 1 (long-time contact):**

- None -

Class 2 and 3 (short-time contact):

Fluorolubes	Perfluorolube oils
Kel-Flo polymers	Halocarbon oils

Class 4 (not suitable):

Aroclors	Silicones
Paraffin	Ucon Hydrolube U-4
RPM hydraulic fluid	Skydrol

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16.5.2 The compatibility of plastics often is not determined by the chemical nature or composition of the polymer itself but is determined by the impurities present in it. For this reason, there may be differences in the compatibility of plastics from different manufacturers and even "batch" variations in a given polymer material from the same manufacturer. Compatibility of plastic and other polymeric or composite materials are therefore usually associated with a manufacturers name. F

16.5.3 All plastic materials must be checked for metal particles, inclusions, etc., prior to use. F

16.5.4 Plastic or elastomeric materials must not be used with hydrogen peroxide at temperatures in excess of 200°F. These materials tend to react (fire and/or detonation) when they are exposed to H_2O_2 at approximately 200° to 250°F. (NAVAER 06-25-501)

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	<u>Reference</u>
16.5.5 Polyethylene is not recommended for concentrations in excess of 70 w/o H ₂ O ₂ .	F
16.5.6 Kel-F, Aclar, and "virgin" Teflon are the most compatible plastic materials at high operating temperatures (up to 200°F).	F
16.5.7 Polyvinylchloride-based materials vary in their reaction with H ₂ O ₂ due to the plasticizer content and other additives, such as fillers and pigments used.	F
16.5.8 Polyvinylchloride plastics will leach chloride ions into the H ₂ O ₂ which will cause corrosion of aluminum even when present in minute quantities.	F
16.5.9 Koro seal 700 (molded) has been extensively used as a gasketing material in low-pressure service.	F
16.5.10 The fluorinated and chlorinated lubricants appear most promising with a Class 2 rating and no impact sensitivity.	P
16.5.11 Many lubricants exhibit impact sensitivity in H ₂ O ₂ .	P

CAUTION

DO NOT USE fluorinated hydrocarbon lubricants for aluminum threads or in conjunction with aluminum with a high surface area in applications where heat may be created. This may lead to detonating reactions.

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SECTION 17 - LIQUID HYDROGEN

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USE FOR TYPED OR WRITTEN MATERIAL ONLY

		<u>Reference</u>
17.0	LIQUID HYDROGEN	
	The liquid hydrogen described herein conforms to MIL-P-27201, 21 May 1959.	
17.1	Nature	
17.1.1	Hydrogen exists in two molecular forms, orthohydrogen and parahydrogen. As the orthohydrogen slowly and spontaneously changes to parahydrogen, heat is released. This increases the venting requirements.	
17.1.2	Liquid hydrogen is noncorrosive but will form combustible mixtures with oxidizers.	C
17.1.3	When allowed to evaporate, it becomes highly combustible with air over a wide range of mixtures.	C
17.1.4	All known substances are essentially insoluble in liquid hydrogen. Helium is possibly soluble to the extent of 1 percent.	C
17.1.5	Hydrogen in either liquid or gaseous form will react violently with strong oxidizers; it will ignite very easily with oxygen and spontaneously with fluorine and chlorine trifluoride.	C
17.1.6	Hydrogen cannot be maintained as a liquid if its temperature rises above -400°F regardless of the confining pressure.	C
17.1.7	Do not expose liquid hydrogen to air or oxygen, as they may condense and solidify in liquid hydrogen and create a potential explosion hazard.	C
17.2	Metals Compatibility	
17.2.1	The ferrous alloys, except for the austenitic nickel-chromium alloys, lose their ductility when subjected to the low temperatures of liquid hydrogen.	C
17.2.2	Contact of dissimilar materials in liquid hydrogen systems or containers must be avoided (galvanic corrosion and/or unequal expansion).	V

	<u>Reference</u>
17.2.3 The ability of materials to retain satisfactory physical properties and withstand thermal stresses caused by large temperature changes is of prime importance.	C
17.2.4 Any materials welded must be subsequently heat-treated to avoid embrittlement during service with liquid hydrogen.	V
17.2.5 Due to time-dependent crack propagation found in fracture toughness tests of materials used in high-pressure hydrogen storage vessels, structures design must investigate all alloys used in their construction for effects of hydrogen environment embrittlement. The following classifications may be used as a guide in regard to metals susceptibility to embrittlement in 10,000 psi hydrogen:	AB, AC
a. <u>Extreme embrittlement</u> : High-strength steels and nickel-based alloys, such as FE-1Ni-4CO-0.25C, Nickel 270, and Inconel 718. (Large reduction of notched strength and unnotched ductility.)	
b. <u>Severe embrittlement</u> : Ductile lower-strength steels, Armco Iron, pure nickel, and titanium base alloys. (Considerable reduction of notched strength and unnotched ductility.)	
c. <u>Slight embrittlement</u> : Nonstable AISI type 300 series stainless steels, beryllium-copper, and pure titanium. (Small reduction of notched strength.)	
d. <u>Negligible embrittlement</u> : Aluminum alloys, stable austentic stainless steels, and copper.	

NOTE

The degree of hydrogen environment embrittlement is more severe at higher hydrogen pressures but can still be considerable at lower pressures with effects extending down to 1 - atmosphere pressure.

Reference

17.2.6 Metals suitable for liquid hydrogen service are as follows: C

Stainless Steel (300 and other Austenitic Series)
 Copper
 Bronze
 Brass
 Monel
 Aluminum
 Everdur

17.2.7 The following metals are not recommended for service with liquid hydrogen: P

Aluminum, 40E	6A14V Titanium
Magnesium	Inconel 718
Lead]
Zinc	See 17.2.5
Iron	
High-Carbon Steel	

17.3 Nonmetals Compatibility

17.3.1 Nonmetals found suitable for liquid hydrogen service are as follows: C, P

Dacron	Lucite
Teflon	Mylar
Kel-F	Nylon
Bakelite	Nitrile and Silicone
Micarta	Rubbers
Asbestos impregnated with Teflon	
Flexitallic filled with Teflon	

17.3.2 The following materials are not recommended for liquid hydrogen service: P

Nature Rubber
 Butyl Rubber
 Neoprene
 Saran
 Polyvinyl chloride
 Polyvinyl alcohol

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		<u>Reference</u>																											
17.3.3	Lubricants are generally not practical in the presence of liquid hydrogen due to the liquid's low temperature.	C																											
17.3.4	Vacuum grease is satisfactory as a sealant with O-rings.	C																											
17.4	Materials Table																												
<p>The following materials have been satisfactorily used for liquid and gaseous hydrogen system components.</p> <table> <thead> <tr> <th><u>COMPONENT</u></th><th><u>LIQUID SERVICE</u></th><th><u>GASEOUS SERVICE</u></th></tr> </thead> <tbody> <tr> <td>Valves-----</td><td>Forged 304 Stainless Steel or brass body with extended bonnet.</td><td>Conventional Material commensurate with pressure requirements</td></tr> <tr> <td>Fittings-----</td><td>Stainless steel bayonet type for vacuum jackets.</td><td>Conventional Material commensurate with pressure requirements</td></tr> <tr> <td>O-rings-----</td><td>Stainless steel type (or Kel-F)</td><td>Rubbers, silicones, elastomers, etc.</td></tr> <tr> <td>Gaskets-----</td><td>Soft aluminum, lead, or annealed copper between serrated flanges.</td><td>Conventional Material commensurate with pressure and sealing requirements</td></tr> <tr> <td>Hoses -----</td><td>Flexible type 316 Stainless Steel</td><td>Aeroquip 1508 (outside) MIL-H-8794 (inside)</td></tr> <tr> <td>Burst Disc Assembly-----</td><td>304 or 304L Stainless Steel Flanges</td><td>Forged Steel flanges</td></tr> <tr> <td>Tubing-----</td><td>304 or 304L Stainless Steel</td><td>Uncoated wrought steel or any 300 series stainless</td></tr> <tr> <td>Dewars -----</td><td>304 or 304L Stainless Steel</td><td></td></tr> </tbody> </table>			<u>COMPONENT</u>	<u>LIQUID SERVICE</u>	<u>GASEOUS SERVICE</u>	Valves-----	Forged 304 Stainless Steel or brass body with extended bonnet.	Conventional Material commensurate with pressure requirements	Fittings-----	Stainless steel bayonet type for vacuum jackets.	Conventional Material commensurate with pressure requirements	O-rings-----	Stainless steel type (or Kel-F)	Rubbers, silicones, elastomers, etc.	Gaskets-----	Soft aluminum, lead, or annealed copper between serrated flanges.	Conventional Material commensurate with pressure and sealing requirements	Hoses -----	Flexible type 316 Stainless Steel	Aeroquip 1508 (outside) MIL-H-8794 (inside)	Burst Disc Assembly-----	304 or 304L Stainless Steel Flanges	Forged Steel flanges	Tubing-----	304 or 304L Stainless Steel	Uncoated wrought steel or any 300 series stainless	Dewars -----	304 or 304L Stainless Steel	
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SECTION 18 - LIQUID NITROGEN

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18.0 LIQUID NITROGEN

18.1 Liquid nitrogen for this purpose has a minimum purity of 99.5 percent, oxygen being the major impurity. The applicable specification is MIL-P-27401A, Type II, 3 April 1962.

18.2 Nature

18.2.1 Nitrogen in either gaseous or liquid form is highly inert. C

18.2.2 It is noncorrosive and will undergo chemical reactions only at very high temperatures. C

18.2.3 Liquid nitrogen is stable to shock, heat, and electrical spark. C

18.2.4 Nitrogen cannot be kept as a liquid if its temperature rises above -232.7°F, regardless of confining pressure. C

18.2.5 Care must be observed to avoid contamination with combustible materials or oxidizers, especially oxygen, if the nitrogen is to be used for pressurizing propellant systems. Liquid nitrogen, if uncontaminated, presents no fire hazard. C

18.2.6 Pure liquid nitrogen presents no explosion hazard. Undetected contamination with combustibles or oxygen could result in a serious explosion if the nitrogen is introduced into a closed system containing substances with which the contaminants can react. C

18.2.7 The hazards to health posed by liquid nitrogen stem from its very low temperature and the possible exclusion of oxygen in enclosed spaces. C

18.3 Metals Compatibility

18.3.1 Metals used with nitrogen should be able to withstand impact shock at low temperatures, as well as the stresses produced by the extremely low temperature. C

18.3.2 Material selection will be based primarily on the intended use, since neither corrosivity nor reactivity are factors for consideration. C

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		<u>Reference</u>
18.3.3	Ordinary carbon steels and most ferritic and martensitic alloy steels are unsuitable for liquid nitrogen service, due to their lack of ductility at low temperatures.	C
18.3.4	The following metals are satisfactory for liquid nitrogen service: Austenitic chrome-nickel steels Stainless steel, 18-8 series Copper Brass Bronze Nickel steel (9%) Monel Copper-Silicon Alloys Aluminum Shredded lead Titanium Molybdenum	C
18.4	Nonmetals Compatibility	
18.4.1	Nonmetals must likewise be selected to withstand the low temperature.	C
18.4.2	The following nonmetals are suitable for this service: Teflon Kel-F Asbestos impregnated with Teflon Cotton-free Asbestos Garlock Packing Nitrile and Silicone Rubber Bakelite Mylar films Selected types of graphite Micarta Nylon Lucite	C, X
18.4.3	Materials used in handling liquid nitrogen must be free of grease, oil, and other combustible materials.	C
18.4.4	Use special lubricants, such as the fluorolubes, unless aluminum is present.	C

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SECTION 19 - LIQUID OXYGEN

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		<u>Reference</u>
19.0	LIQUID OXYGEN (LOX)	
19.1	The material considered here for propellant use is liquid oxygen conforming to Specification MIL-O-25508, 16 March 1966.	
19.2	Nature	
19.2.1	Liquid oxygen (LOX) supports and rapidly accelerates the combustion of all flammable materials to an explosive degree.	Z
19.2.2	LOX may react violently in contact with combustible vapors or solids under suitable conditions of temperature and pressure, and in the presence of a source of ignition such as static electricity, flames, sparks, and shock waves from impact.	Z
19.2.3	Some of the commonly known materials which may cause a fire or explosion in contact with liquid oxygen are: oil, grease, solvents, tars, asphalt, gasoline, kerosene, JP-4 fuel, alcohol, acetone, propane, butane, wood, cloth, paper, cork, cotton, paint, and metal in the form of powder or shavings.	C, E
19.2.4	Mixing LOX with fuels presents a dangerous explosion hazard. Frozen-fuel/liquid-oxygen mixtures are extremely shock-sensitive.	C
19.2.5	The prime consideration in choosing materials for use with liquid oxygen relates to their physical properties at low temperature and their ability to withstand stress concentrations, including those resulting from sudden temperature changes.	C
19.3	Metals Compatibility	
19.3.1	All ferrous and aluminum based alloys tested to date are considered compatible with LOX; although the ferrous alloys, except for the austenitic nickel-chromium alloys, lose their ductility when subjected to the low temperatures and may be considered too brittle for this service.	C
19.3.2	The 300 series stainless steels can be used where design requirements accommodate a thicker section to offset lower strength properties.	T

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	<u>Reference</u>
19.3.3 Where high strength is a requisite, hardenable austenitic alloys (A-286) and hardenable nickel base alloys are acceptable. However, difficulty in the welding of thick sections creates a use limitation.	T
19.3.1 The semi-austenitic stainless steels offer the advantages of highest strength combined with corrosion resistance and weldability. (Example: AM-350 steel in the SCT 1050 heat treated condition.)	T
19.3.5 The following metals are acceptable for service with LOX: Stainless Steel, series 18-8 preferred Copper Bronze Brass Monel Everdur Aluminum (see Para. 19.3.6)	C
19.3.6 Freshly abraded aluminum or aluminum which has been stripped of its protective oxide film is impact sensitive. Thus, although the natural oxide film on aluminum is sufficient to make it impact insensitive, any action which breaks or removes the film from aluminum while in LOX constitutes a hazardous situation.	T
19.3.7 Of the aluminum base materials, 7075-T6 and 2024-T4 wrought alloys have been used where high strength and low weight are required. The 6061-T6 aluminum has application in pressure tight case components.	AE
19.3.8 The inherent compatibility of the common aluminum alloys is not affected adversely by anodizing or by two proprietary surface treatments ("Iridite" and "Alodine").	T
19.3.9 Some samples of aluminum which have been anodized and dyed have proven to be impact sensitive. Thus, any dyed aluminum or new processes of dyeing and/or conversion coating aluminum should be tested to insure LOX compatibility.	T
19.3.10 The ignition-sensitive alloys in an oxygen system include the alloys of titanium, zirconium, thorium, uranium, lead, tin, and magnesium.	Q

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19.3.11 A number of secondary energy input sources have been shown to cause ignition of these sensitive alloys in oxygen systems. These sources also probably produce a fresh metal surface and are identified as follows:

In Gaseous Oxygen

Electrical spark
Puncture
Stress rupture
Explosive shock

In Liquid Oxygen

Mechanical impact
Explosive shock
Puncture

19.3.12 All metals, with the possible exceptions of gold and platinum, can be expected to ignite in oxygen at some elevated temperature.

19.3.13 All titanium alloys tested have been extremely sensitive to impact.

19.3.14 Coatings which reduced titanium reactivity during impact or shock tests were not beneficial under puncture conditions.

19.3.15 Magnesium alloys generally are somewhat more susceptible to reaction with oxygen than aluminum, but far less than titanium.

19.3.16 Electrodeposited coatings on steel generally are LOX compatible (cadmium, copper, nickel, chrome). However, tin plated materials have been impact sensitive.

19.3.17 Lead and lead based solders generally are impact sensitive in LOX.

19.3.18 All high melting silver solders tested have proven satisfactory.

19.3.19 Any soft solders intended for application on LOX hardware should be tested individually.

19.4 Nonmetals Compatibility

Reference

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USE FOR TYPEWRITTEN MATERIAL ONLY

	<u>Reference</u>																														
19.4.1	All natural and non-fluorinated synthetic rubbers tested to date, including a number of silicone elastomers, have proven impact sensitive to varying degrees. Most common plastics are impact sensitive to a varying degree. T																														
19.4.2	The impact sensitivity of these nonmetals varies to a marked degree with the nature and extent of the plasticizer and additives used. Thus, impact testing of the particular material is necessary to insure LOX compatibility. T																														
19.4.3	The following list provides some of the materials <u>not</u> recommended for LOX service due to impact sensitivity: T, X																														
	<table> <tbody> <tr><td>Buna N</td><td>Plaskon Alkyd 400</td></tr> <tr><td>Butyl Rubber</td><td>Plexiglas</td></tr> <tr><td>Epocast</td><td>Polyamide</td></tr> <tr><td>Epoxy Resins</td><td>Polycarbonate Resin</td></tr> <tr><td>Fluoro Resins (LANKOTE)</td><td>Polyester-Glass</td></tr> <tr><td>Glyptal</td><td>Polyester Film</td></tr> <tr><td>Hypalon 20</td><td>Polyethylene</td></tr> <tr><td>Hypalon Adhesive</td><td>Polyvinyl Chloride</td></tr> <tr><td>Laminac 4128</td><td>Gum Rubber</td></tr> <tr><td>Melamine</td><td>Scotch Tape</td></tr> <tr><td>Mylar</td><td>Silastic</td></tr> <tr><td>Neoprene</td><td>Silicone</td></tr> <tr><td>Nylon</td><td>Tedlar</td></tr> <tr><td>Phenolic</td><td>Thiokol Rubber</td></tr> <tr><td>Fluoro Rubber</td><td>Vinyl</td></tr> </tbody> </table>	Buna N	Plaskon Alkyd 400	Butyl Rubber	Plexiglas	Epocast	Polyamide	Epoxy Resins	Polycarbonate Resin	Fluoro Resins (LANKOTE)	Polyester-Glass	Glyptal	Polyester Film	Hypalon 20	Polyethylene	Hypalon Adhesive	Polyvinyl Chloride	Laminac 4128	Gum Rubber	Melamine	Scotch Tape	Mylar	Silastic	Neoprene	Silicone	Nylon	Tedlar	Phenolic	Thiokol Rubber	Fluoro Rubber	Vinyl
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Phenolic	Thiokol Rubber																														
Fluoro Rubber	Vinyl																														
19.4.4	The materials below have been found insensitive to impact with LOX. C, T, X																														
	<table> <tbody> <tr><td>Teflon</td><td>Fluorocarbon ether (FC75)</td></tr> <tr><td>Kel-F</td><td>Perfluorocarbons</td></tr> <tr><td>Pure Asbestos</td><td>Polybutadiene</td></tr> <tr><td>Special Silicone Rubbers</td><td>Polychloroprene</td></tr> <tr><td>Chlorofluorocarbon</td><td>Polypropylene</td></tr> <tr><td>Fluorinated hydrocarbon</td><td>Vitron A</td></tr> <tr><td>Fluor asbestos A, B</td><td></td></tr> <tr><td>Fluorosilicone</td><td></td></tr> </tbody> </table>	Teflon	Fluorocarbon ether (FC75)	Kel-F	Perfluorocarbons	Pure Asbestos	Polybutadiene	Special Silicone Rubbers	Polychloroprene	Chlorofluorocarbon	Polypropylene	Fluorinated hydrocarbon	Vitron A	Fluor asbestos A, B		Fluorosilicone															
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Fluor asbestos A, B																															
Fluorosilicone																															

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	<u>Reference</u>
19.4.5 Owing to their resistance to the strong oxidizing properties of oxygen and the extremely low temperatures encountered, the following materials from the above list are approved for total service with LOX:	C
Teflon	
Kel-F	
Pure Asbestos	
Special Silicone Rubbers	
19.4.6 No fully satisfactory adhesive has been found for LOX use.	T
19.4.7 Epoxy resins and cements are violently sensitive to impact and must be excluded completely from LOX service. Most silicone adhesives are impact sensitive.	T
19.4.8 Petroleum-base lubricants must not be used for LOX service.	C
19.4.9 Conventional silicone greases and fluids constitute a hazard due to impact and must not be used.	T
19.4.10 All completely fluorinated and/or chlorinated fluids and greases tested to date have proven satisfactory for LOX service from the standpoint of impact sensitivity.	T
<u>NOTE</u>	
Chlorofluorocarbon oils and greases ("Fluorolubes," "Kel-Fs," and "Halo-carbons") are not to be used under conditions of high shear involving aluminum.	T
19.4.11 The perfluoro-trialkyl amine based lubricants generally were LOX compatible ("PD-817" and "PD-788").	T
19.4.12 The polymeric perfluoro base greases are compatible with strong oxidizing materials such as LOX.	AE
19.4.13 A proprietary sealant, "Anderol X-133," is satisfactory from the standpoint of LOX compatibility, but is highly corrosive to aluminum alloys 5085, 6061, and 2024.	T

Reference

19.4.14 An asbestos-synthetic rubber mixture, "Allpax 500," treated with chlorofluorocarbon fluid, has proven to be a satisfactory gasket material with LOX. T

19.4.15 The gasket materials, Fluorogreen E-600 and E-609, appear satisfactory for use with LOX. T

CAUTION

It is stressed that even the recommended packing and gasket materials vary in acceptability from one batch to another; therefore, samples from each batch intended for LOX service should be tested and qualified prior to use.

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SECTION 20 - MONOMETHYLHYDRAZINE

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		<u>Reference</u>
20.0	MONOMETHYLHYDRAZINE (MMH)	
20.1	Propellant-grade monomethylhydrazine (MMH) contains a minimum of 99 percent MMH, CH_3NNH_2 , the remainder being primarily water. This propellant-grade described conforms to MIL-P-27404, 3 April 1962.	
20.2	Nature	
20.2.1	MMH is a strong reducing agent, weakly alkaline, and very hygroscopic.	C
20.2.2	It will react with carbon dioxide and oxygen in air.	C
20.2.3	Materials with large surface areas (e.g., rags, cotton waste, sawdust and excelsior) that have absorbed MMH may spontaneously heat and ignite.	C
20.2.4	MMH vapor is flammable in all concentrations in air between 2.5 and 98 percent.	C
20.2.5	It is hypergolic with some oxidants, such as hydrogen peroxide, nitrogen tetroxide, fluorine, and nitric acid.	C
20.2.6	A film of MMH in contact with metallic oxides, such as those of iron, copper, lead, and manganese, causes MMH to decompose, and may ignite owing to the chemical heat of decomposition.	C
20.2.7	Liquid MMH is not sensitive to impact or friction.	C
20.2.8	MMH shall be stored under an atmosphere of nitrogen at all times.	C
20.2.9	MMH is a volatile, mobile liquid. Since it is alkaline, it is caustic to skin and eyes.	C
20.3	Metals Compatibility	
20.3.1	MMH is compatible with, and may be handled in, most common metals under a wide variety of conditions.	C
20.3.2	Equipment for storage and shipment should be made of mild steel.	C

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	<u>Reference</u>
20.3.3 Metals which are satisfactory for MMH service are as follows:	C, P
Stainless steels 303, 304, 321, and 347	
4130 Steel	
Aluminum alloys to 160°F	
Aerobraze-I, C-62, and EASY-FLOW No. 45 for brazing applications	
Durimet-20	
20.3.4 Of the stainless steel selections listed, the 304 and 347 series are preferred.	C
20.4 Nonmetals Compatibility	C
20.4.1 Preferred materials include the following:	C
Teflon	
Kel-F (Unplasticized)	
Polyethylene (High density)	
Garlock 735	
Some Silicone Rubbers	
20.4.2 Because of MMH's solvent properties, no completely suitable lubricant has yet been found.	C
20.4.3 Lubricant experience with hydrazine and UDMH suggests that Dow Corning 11 Compound (silicone), Fluorolube GR-470, and Kel-F grease may be used.	C
20.4.4 Kel-F and possibly Teflon have shown some degree of reactivity (decomposition) with MMH at 70°C.	2-5023

SECTION 21 - NITRIC ACID, FUMING

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	<u>Reference</u>
21.0 NITRIC ACID, FUMING	
21.1 The propellant-grade nitric acid described herein conforms to MIL-P-7254E, 17 August 1961.	
21.2 Common terminology for types of fuming nitric acids discussed are as follows:	
I White fuming nitric acid (WFNA)	
I A Inhibited white fuming nitric acid (IWFNA)	
III Red fuming nitric acid (RFNA)	
III A, B Inhibited red fuming nitric acid (IRFNA)	
21.3 Nature	
21.3.1 The fuming nitric acids are highly corrosive oxidizing agents and will vigorously attack most metals.	C
21.3.2 With organic liquids, such as oil, the amines, furanes, and certain vinyl compounds, nitric acid will react explosively.	E
21.3.3 The nitric acids will react with sea water, releasing large quantities of nitrogen oxides which are toxic.	C
21.3.4 These nitric acids are hygroscopic.	C
21.3.5 Nitric acid is stable to all types of mechanical shock and impact.	C
21.3.6 Nitric acids by themselves will not burn; however, the fumes liberated by the acids support combustion.	C
21.3.7 Upon contact with certain fuels (such as the hydrazines or furfuryl alcohol) nitric acid will react violently. Nitric acid will form explosive mixtures with nonhypergolic fuels (such as hydrocarbons) and with hypergolic fuels if either the fuels or the nitric acid contain excessive water.	C
21.4 Metals Compatibility	

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Reference

21.4.1 The following list are approved metals for use with fuming nitric acids:

C

<u>Aluminum (types)</u>	<u>Stainless Steel (types)</u>
1060	347
EC	19-9 DL
1100	19-9 DX
3003	304 ELC
3004	321
6061	303
5052	316
5154	

21.4.2 All other ferrous and nonferrous metals and their alloys are prohibited, because they react with fuming nitric acid, producing toxic oxides of nitrogen, as well as failures from corrosion.

C

CAUTION

When in contact with red fuming nitric acid (RFNA), titanium metals, and alloys of which titanium is a major constituent, present the hazards of explosion and stress corrosion cracking.

C, R

21.4.3 Cold worked 304 stainless steel, normally resistant to attack by red fuming nitric acid, when welded undergoes intergranular corrosion in the weld and heat affected areas when exposed to fuming nitric acid.

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21.4.4 Stainless Steel 410 when subjected to certain heat treatment conditions and then placed under a stress condition undergoes rapid failure due to stress corrosion cracking when exposed to fuming nitric acid.

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21.5 Nonmetals Compatibility

21.5.1 The following are nonmetals approved for service with the fuming nitric acids:

C, X

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	<u>Reference</u>
Kel-F	
Teflon	
Polyethylene	
Resin-X; concrete protective coating	
Epoxy, Epon 400 XR61 coating	
Exon 400 XR61	
Fluorocarbon Plaskon	
21.5.2 Any type of nitric acid containing hydrogen fluoride must not be shipped in glass containers.	C
21.5.3 Gaskets of the following type are acceptable for use with fuming nitric acid:	C
Sheet Teflon	
Kel-F	
Geotze-type aluminum	
Teflon-sheathed asbestos (envelope)	
Corrugated aluminum with asbestos-filled depressions	
21.5.4 Three lubricants approved for use with fuming nitric acids are as follows:	C
Nordcoseal-147-S	
Fluorolube	
Perfluorocarbons	
21.5.5 The following plastics have been evaluated and found usable in repeated short-time contact with red fuming nitric acid (RFNA).	X
Opalon 75219	
Phenoline 315	
Poly FBA (room temperature)	
Polyisobutylene-polyethylene blends	
Saran 281 (room temperature)	

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		<u>Reference</u>
21.5.6	The following plastics and elastomers are <u>not recommended</u> for any use with <u>RFNA</u> :	X
	Acrylon rubber BA-12 and EA-5	Phenol formaldehyde
	Acrylonitrile rubber	Phenol furfural
	Allyl resins	Pliogard, coating
	Butyl, Enjay 218 (and w/fillers)	Polyacrylic ester resins
	Cellulose compounds	Polyester resins
	Chlorinated rubber	Polystyrene
	Diallyl phthalate	Polyvinyl carbazole resins
	Epoxy resins	Polytrifluorochloroethylene
	Furane resin	Rubber, hard
	Hycar; Hycar 2202, coating	Sarankote, coating
	Inorganic plastic	Silicone
	Irrathene-101, -102	Styrene
	Melamine formaldehyde	Urea formaldehyde
	Methyl methacrylate resins	Vinyl butyral resins
	Neoprene, coating	Vinyl alcohol resins
	Nylon Zytel	Vinyl chloride resins
	Nylon	Vinyl formal resins
21.5.7	The following plastics and elastomers have been evaluated with <u>IRFNA</u> and are <u>not recommended</u> for any use with this service:	X
	Dacron	Styrene
	Hi Fax	Teslar 30; Teslar 40
	Kodapar II	Ultron
	Lexan	Vinyl, plasticized
	Mylar	Vitron A-HV
	Spauldite	
21.5.8	The following plastics and elastomers have been evaluated with <u>WFNA</u> and are <u>not recommended</u> for any use with this service:	X
	Epoxy, Epon 470 and Epon 471	Phenolic resins
	Furane resin	Rubber, hard
	Garlock 230, 233	Sarankote A-1098
	Heresite Industrial	Silastic-167, -180, -181
	Koro-seal	Tygon
	Lankote Fluoro B	Vinylite
	Lankote - KB	

SECTION 22 - NITROGEN TETROXIDE

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	<u>Reference</u>
22.0	NITROGEN TETROXIDE, N_2O_4
22.1	Propellant nitrogen tetroxide, MIL-P-26539A, 31 July 1961, contains a minimum purity of 99.5 percent by weight and contains no more than 0.1 percent water equivalent.
22.2	Nature
22.2.1	Nitrogen tetroxide is a corrosive oxidizing agent. C
22.2.2	It may react with combustible materials and is hypergolic with UDMH, hydrazine, aniline, and furfuryl alcohol. C
22.2.3	N_2O_4 is not sensitive to mechanical shock, heat, or detonation. It is nonflammable with air, but it can support combustion. It is highly toxic. C
22.2.4	Nitrogen tetroxide in water reacts to form nitric and nitrous acids. The nitrous acid decomposes, forming additional nitric acid and evolving nitric oxide. C
22.3	Metals Compatibility
22.3.1	Although nitrogen tetroxide at ordinary temperatures and pressure is not corrosive to most common metals, the selection of metals for this service must be governed by the oxidizer's moisture content. C
22.3.2	Nitrogen tetroxide reacts with water to form nitric acid which is a corrosive agent to most materials of construction. M
22.3.3	The following metals are suitable for this service: C, M

When moisture is 0.1% or less

Carbon steel
 Aluminum alloys 1100, 5052, 6061, 6066, 356, B356,
 and TENS 50
 Stainless steel 300 and 400 series
 Stainless steel 17-4 PH, 17-7 PH
 Nickel
 Inconel-X

Under wet conditions (Moisture content greater than 0.1%)

300 series stainless steel only

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	<u>Reference</u>
22.3.4 The following metals have been found to be incompatible with nitrogen tetroxide and <u>must not be used</u> :	M
Aluminum 2024	Zinc
Aluminum 7075	Silver
K-Monel	Titanium
Brass	Cadmium
Bronze	Hastelloy
Copper (see para. 22.3.20)	EZ Flow 45 Braze
22.3.5 Nitrogen tetroxide per MIL-P-26539A (oxygenated) has been found unsuitable for long term (greater than four months) storage in types 317 and A286 stainless steel thin walled containers (0.030 inch or less).	M
22.3.6 Type A286 stainless steel with a nitric-hydrofluoric pickled surface is more susceptible to intergranular corrosive attack by oxygenated nitrogen tetroxide than a nitric passivated surface. This attack is accelerated by applied stress and can cause a fracture. The Arde type 301 stainless steel is also susceptible to surface cracking in oxygenated nitrogen tetroxide when stressed.	M
22.3.7 Stainless Steel types Arde 301, 304L, 347, and A286 were found compatible with nitrogen tetroxide inhibited with nitric oxide when tested at 150°F for up to six months.	J
22.3.8 The 400 series stainless steels are attacked slightly more than the 300 series, but can be used in the heat treated condition where strength or hardness is required.	J
22.3.9 The precipitation hardening stainless alloys (17-7 and 17-4) have found use where more strength is required than the 18-8 steels can provide and the hardness of the 400 series steels are not required.	J
22.3.10 Titanium must be avoided because of the possibilities of impact sensitivity in the presence of a strong oxidizing agent.	J
22.3.11 Aluminum alloys rank next to the 18-8 stainless steel alloys in corrosion resistance when exposed to dry N_2O_4 . However, when exposed to water-contaminated nitrogen tetroxide, the corrosion rate is greatly increased.	J

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	<u>Reference</u>
22.3.12 Aluminum alloys are subject to accelerated corrosion when coupled with more noble metals, such as the stainless steels. Designs that couple small areas of aluminum with large areas of stainless steel must be avoided.	Y
22.3.13 Anodized coatings are not generally resistant to water-contaminated N_2O_4 .	J
22.3.14 At present, the only coatings considered satisfactory for nitrogen tetroxide service are: (1) chromium deposited directly over a corrosion-resistant base metal; (2) hard-faced surfaces provided by nickel-chromium and iron-chromium alloys; and (3) tungsten carbide.	Y
22.3.15 Tungsten carbide surfaces are specified for wear surfaces of rotary seals.	Y
22.3.16 Chromium electro-deposited directly over aluminum is satisfactory for some applications.	Y
22.3.17 Type II (sulfuric acid) anodize is generally specified for exterior surfaces of aluminum hardware for resistance to nitrogen tetroxide fumes and splash and to humidity and other atmospheric contaminants.	Y
22.3.18 Brazing materials found suitable for direct contact with N_2O_4 are IM Nicrobraz (AMS 4775), Aerobraz-1 (nickel-gold-palladium), and C-62 (Manganese base).	Y
22.3.19 Silver solders and other low-melt solders are not satisfactory for direct exposure to nitrogen tetroxide, but may be used for limited exposure to N_2O_4 fumes or splash.	Y
22.3.20 Because of their poor resistance to nitric acid formed in moist N_2O_4 , copper and copper alloys are not recommended for use. Although Berylco 25, a beryllium-copper alloy, exhibited good corrosion resistance to dry N_2O_4 , caution is advised in its use with moist N_2O_4 .	B
22.3.21 Haynes Stellites No. 6K, 21, and 25 exhibit good corrosion resistance with nitrogen tetroxide.	B
22.4 Nonmetals Compatibility	

	<u>Reference</u>
22.4.1 The following nonmetals may be used with N_2O_4 :	C, J, M, X
Armalon 7700; 7700B	Graphite (dry)
Asbestos (cotton-free)	Kynar
Bakelite DPDB-6169	Molycote (binderless)
Carboxylnitroso terpolymer	NA2-205-2 (Alochlor-1254)
Ceramic (acid-resistant)	Polyethylene (limited use)
Flexitalic	Teflon
Fluorobestos	Teflon 100-X
Fluorogreen	Pyrex glass
Genetron GCX-3B	Vitron A and B (limited use)
Genetron XE-2B	Kel-F Elastomer (limited use)
	Koroseal (limited use)
	Saran (limited use)
22.4.2 The nonmetals listed below have been found incompatible with nitrogen tetroxide and must not be used:	J, M, X
Acrylic nitrocellulose	Lexan
Alkyd No. 4	Marlex 50; Marlex 5003
Buna - N	Micarta
Butyl rubber	Mylar
Butyl compounds	Neoprene
Capran 391	Nitroso rubbers
Kodapak II	Nylon
Chloroprene	Opalon
Cohrplastic 500	Paraplex P-43
Co-Polymer P-200G	Penton
Cyanopropyl silicone	Plexiglas
Dacron	Polypropylene
Delrin	Polyurethane
Dynamar	Polyvinyl chloride
Epoxy compounds	Rubber, natural
Fairprene 5159	Silicones
Fluorel	Syrene
Garlock 22, 900	Vinyl
Genetron GC	Johns-Mansville Packing
H-film	No. 60
HT 424	Johns-Mansville Packing
Hi Fax	No. 76
Hycar 2202	
Hypalon	
Hypalon 20	

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	<u>Reference</u>
22.4.3 The butyl-phenolic elastomers B496-7RV, 11092-3A, and TC 419-19A are satisfactory for dynamic or static short term (7 day predicted) service with nitrogen tetroxide.	X
22.4.4 The resin cured butyl 112 elastomer (Thiokol Chemical Corp.) is suitable for dynamic application (i.e., pulsating diaphragm) with liquid N_2O_4 at room temperature. This resin cured butyl is satisfactory in nitrogen tetroxide for approximately 30 days.	AE, AF
22.4.5 Most elastomeric materials are completely disintegrated by nitrogen tetroxide within a few hours.	J
22.4.6 Teflon is the best available material for seals, gaskets, and O-rings that are used in nitrogen tetroxide for extended periods of time.	Y
22.4.7 Teflon and metal combinations (RACO, Flexitallic, Spiral-italic, K-seal, etc.) have been used successfully as pipe flange seals.	Y
22.4.8 Teflon, graphite, and Kel-F300 have been satisfactory for dynamic seals, but it is recommended that dynamic seals be avoided whenever possible.	Y
22.4.9 Kel-F300, a perhalogenated plastic, has been used for dynamic seals; however, it absorbs nitrogen tetroxide rapidly and exudes it very slowly and its use should be limited.	Y
22.4.10 Teflon, Kel-F, some vinyls, polypropylene, polyethylene, and chlorinated polyether have adequate resistance for semi-rigid insulation that will be subjected to occasional spillage or vapor exposure.	Y
22.4.11 Polyethylene and polypropylene shall be used only for brief nitrogen tetroxide exposure, since they become slowly oxidized.	Y
22.4.12 Polyethylenes are disintegrated with nitrogen tetroxide exposure exceeding four days.	J

CAUTION

Exercise caution in using either chlorinated polyether or polyvinyl chloride plastics. There is some evidence to indicate that chlorinated polyethers are impact-sensitive.

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	<u>Reference</u>
22.4.13 Fluorosilicone rubber (Vitron A and B) is unaffected by short durations, but a one-hour exposure reduced its tensile strength 15 percent. This effect is limiting, however, and this compound may be used up to two months duration.	J
22.4.14 Ethylene-propylene rubber has been used in this fluid when the exposures have been less than 3 days.	AE
22.4.15 In the limited areas where elastomeric O-rings are used, LS-53 fluorosilicone-based materials have been used for short-term service.	Y
22.4.16 Hypalon absorbs nitrogen tetroxide and shall not be used where moisture content exceeds 0.1 percent.	J
22.4.17 Koroseal and Saran are reported as "useful," although somewhat limited in service life.	J
22.4.18 Good quality ceramic bodies and Pyrex are satisfactory for handling nitrogen tetroxide both in the wet or dry condition.	J
22.4.19 Dry graphite, graphite-waterglass, and Teflon tape are recommended for use on pipe thread-type closures and joints.	J
22.4.20 The following lubricants and cements are incompatible with nitrogen tetroxide service and shall be avoided:	J, M
<p>Hydrocarbon lubricants Conventional "pipe dope" compounds Litharge and glycerin Epoxy cements Glyptal cements Dow Corning lubricant No. 55 (MIL-G-4343) Oxylube MIL-L-6086 MIL-L-25336 DC-11</p>	
22.4.21 The below listed lubricants are approved for service with nitrogen tetroxide:	C, J, Y
<p>Fluorolube series Nordcoseal-147 and DC 234S Teflon tape NA 2-205-2 (Alochlor-1254)</p>	
<p>Graphite (dry) Molycote Z (binderless) Redel Reddy lube 100 and 200</p>	

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Reference22.5 TABLE I**MATERIALS FOR USE AS SEALS, GASKETS, AND O-RINGS
IN NITROGEN TETROXIDE SERVICES:**

Y

<u>APPLICATION</u>	<u>MATERIAL</u>
Dynamic or static extended service:	Fluorocarbons: Teflon 100 Teflon I Polychlorotrifluoroethylene Kel-F 300 Kel-F-500 Kel-F 500E
	Vinylidene Fluoride Kynar
Dynamic or static short-term service (hours):	Polyethylene Marlex 50 Polypropylene Pro-fax
Static service short-term (7 day max.):	Butyl-phenolic Elastomer B496-7RV 11092-3A TC 419-19A

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Reference22.6 TABLE IILUBRICANTS AND SEALANTS FOR NITROGEN TETROXIDE
SERVICE:

Y

MATERIAL

Halogenated oils:

Alochlor 1254 oil
Chlorotrifluoroethylene oils

Silicone greases:

Valve Seal
High vacuum and DC-11
XC-150

Chlorotrifluoroethylene greases

Carbon:

Flake Graphite
Dag Dispersion 217

Molybdenum Disulfide:

Molykote

Chlorotrifluoroethylene Waxes

Proprietary:

LOX Safe
Oxylube
Reddy Lube 100
Reddy Lube 200

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Reference22.7 TABLE III

ADHESIVES, COATINGS, AND TAPES (for splash or brief,
intermittent exposure):

Y

MATERIAL

Adhesives and Coatings:

Phenolic:

Travarno F-120

Novolac-Type Epoxy:

Epon 1031 w/ BF_3

Epoxy:

X-Epon 4-184

X-Epon 5-100-1

Inorganic:

Sauereisen P-1

Sauereisen 7 (silica base)

Sauereisen Conductulates (graphite base)

Coatings:

Phenolic-Epoxy-Silicone:

PT-201G

Fluorocarbons:

Teflon w/steel primer

Polyethylene:

Marlex-50

Chlorinated Polyether:

Penton

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22.7 TABLE III (Continued)Reference

Y

MATERIAL

Coatings: (Continued)

Proprietary:

DA-9

Tapes:

Metallic Backed:

420 lead foil
425 aluminum foil
Y-9040, aluminum foil
7402-96171, aluminum foil

Teflon Backed:

549
7503
X-111
SL 28011, Lot 303

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Reference22.8 TABLE IV

MATERIALS FOR USE AS INSULATION (splash or brief, intermittent exposure):

Y

<u>APPLICATION</u>	<u>MATERIAL</u>
Thermal and Electrical for over 1000°F	Inorganic: Sauereisen No. 7 paste Sauereisen No. 39 Sauereisen P-1 Sauereisen P-6
Thermal and Electrical for 500°F and up	Fluorocarbons: Teflons
	Phenolic: SC 1008 F-120-55
	Novolac Type Epoxy: Epon 1031 w/BF ₃
Thermal and Electrical under 500°F	Materials listed in Table I

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SECTION 23 - PENTABORANE

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SECTION 23 - PENTABORANE

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		<u>Reference</u>
23.0	PENTABORANE, B_5H_9	
23.1	Considered here is commercial pentaborane with a minimum purity of 99 percent. The major impurities are other boron hydrides.	
23.2	Nature	
23.2.1	Pentaborane is a very toxic, volatile, high energy fuel. The material may flame spontaneously on contact with air.	C, I
23.2.2	Pentaborane being pyrophoric, explosive concentrations of vapor are not normally present in air. The pentaborane auto-ignition temperature in air has been established at about 77°F.	C, N
23.2.4	In the absence of air or contaminants, pentaborane is stable at room temperature.	C
23.2.5	Storage and transfer systems must be kept clean, as pentaborane will form solid or gumming deposits with lubricants, dirts, most solvents, water, cleaning compounds, and refrigerants. Many of these deposits are impact sensitive.	I
23.2.6	It may react explosively or will form shock-sensitive solutions with highly halogenated or oxygenated solvents and carbon disulfide.	C
23.2.7	Pentaborane reacts with hydrazine and other amines. An external ignition source is required to react pentaborane with hydrazine.	C, N
23.2.8	It is hypergolic with high-energy oxidizers, such as chlorine trifluoride, at atmospheric pressures.	C, N
23.3	Metals Compatibility	
23.3.1	Most of the common metals are compatible with pentaborane. However, the oxides of these metals are reactive to pentaborane and precautions must be taken to prevent their formation.	I

Reference

23.3.2 The following metals have been found to be satisfactory for use with pentaborane: C, I

Aluminum and Aluminum Alloys

5052-S
6061-T6
7075-T6
2024-T3
3003-H14
356-T6
Anodize

Corrosion Resistant

Stainless Steel, 18-8 Series
Low-Carbon Steel
K-Monel
Monel M-8330-B
Nickel
Nichrome "V"
Magnesium, Fed-QQ-M-44A
Magnesium, Fed-QQ-M-56-A263
Titanium C-130-AM and C-110-AM
Copper
Brass
Hastelloy

23.3.3 Carbon steel piping and components are not recommended for service in pentaborane. I

23.3.4 Brazing and soldering techniques are not recommended for application in pentaborane systems. The joints produced by these methods are usually incompatible with the propellant. I

23.4 Nonmetal Compatibility

23.4.1 Nearly all of the common rubber compounds swell when exposed to pentaborane. I

23.4.2 Pentaborane will hydrolyze slowly in the presence of water to form boric acid and hydrogen. Any material containing free or bound water will show some degree of reaction with pentaborane. I

23.4.3 Pentaborane is miscible with many inert organic compounds. I

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Reference

23.4.4 The following nonmetals are approved for use with pentaborane: C, I

Kel-F
Kel-F-5500
Teflon
Fluorosilicone rubbers
Fluoroflex "F"
Glass
Vitron "A" and "B"
Pyrex
Dry Asbestos
Garlock 230
Carbon
Polyethylene
Polypropylene

23.4.5 The following lubricants may be used with pentaborane: C

Graphitar No. 39
Hercules No. 571 Kaobestos
Rockwell-Nordstrom Lube No. 921
Gulf Harmony Oil No.'s 44 and 69

23.4.6 The use of the following materials with pentaborane is prohibited: C, I

Nylon	Foam glass (with binder)
Saran	Vinylidene plastics
Mylar	Rockwell-Nordstrom Lubes Nos.
Tygon	833, P-21, 860, 386, 852-S, P-55, and 942-S
Silicones	Graphite and Carbon (with binders)
Neoprene	GRS rubber
Epoxy cements	Buna rubber
Polyurethane	Butyl rubber
Water-base lubricants	Natural rubber

23.4.7 The following is a partial list of materials which will form shock-sensitive mixtures with pentaborane: C, N, X

Reference

Acetone	Thiokol rubber
Aldehydes	Ammonium chlorate
Alkyl chloride	Dimethyl ether
Carbon tetrachloride	Acrolein
Chloroform	Ansul ethers
Dioxane	Acetaldazine
Ethyl acetate	Aldol
Freons	2 - (chloromethyl) ether
Halogenated compounds	3 - Chloropropene
Ketones	1, 4 - Dibromoethane
Trichlorethane	Methylene bromide
Trichlorethylene	Methylene iodide
Methylene chloride	

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SECTION 24 - PERCHLORYL FLUORIDE

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	<u>Reference</u>
24.0 PERCHLORYL FLUORIDE, $C_{10}F_3$	
24.1 The perchloryl fluoride discussed herein is of 99 percent minimum purity with a maximum of 0.02 percent moisture.	
24.2 Nature	
24.2.1 Perchloryl fluoride is a strong oxidizing agent. Under most conditions, it is relatively nonreactive; temperature is the controlling factor in reaction rate.	C
24.2.2 Perchloryl fluoride is a thermally stable gas at room temperatures and can be stored in liquid form under pressure.	C
24.2.3 It is nonflammable, but supports combustion, and is a strong oxidizing agent.	C
24.2.4 It may form explosive mixtures with some fuels, such as amines or hydrazine.	C
24.2.5 With porous materials such as activated carbon, foamed rubbers, plastic foams, activated alumina, etc., explosive mixtures may be formed or spontaneous ignition may occur. When combined with porous organic materials, such as sawdust and charcoal, it may yield a possibly shock-sensitive explosive mixture.	C
24.2.6 In poorly ventilated spaces, perchloryl fluoride vapor can form a mixture with flammable vapors that can be exploded by static electricity, electrical spark, or flame.	C
24.3 Metals Compatibility	
24.3.1 Although at ordinary temperatures perchloryl fluoride is not corrosive to most common metals, moisture content of the perchloryl fluoride should be the governing factor in selecting a metal for this service.	C
24.3.2 Grenade or cylinder-perforation tests resulted in detonation of titanium in liquid and gaseous perchloryl fluoride. Titanium also ignited under impact in perchloryl fluoride but the burning was not sustained.	P

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Reference

24.3.3	The readily oxidizable metals will burn in perchloryl fluoride under severe conditions; surface area is a major factor. Powders and fillings burn readily, while foil or sheet is more resistant.	C
24.3.4	The following metals are approved for the indicated service:	C
	<u>Anhydrous</u>	<u>Moist</u>
	Carbon Steel	Stainless Steel, 304,
	Aluminum	310, 314
	Stainless Steel	Hastelloy
	Copper	Tantalum
	Brass	Durimet "T"
	Bronze	Durimet-20
24.4	Nonmetals Compatibility	
24.4.1	Owing to the lack of operational and long-term data, the only nonmetal materials that can be recommended for severe service with perchloryl fluoride in a situation where pressure or flow phenomena may initiate combustion or detonation are Kel-F and Teflon.	C
24.4.2	The following materials are limited to repeated short term use in the perchloryl fluoride gas system: (Contact not to exceed 4 hours at 160°F or 1 week at 70°F)	P, X
	Epoxy resins	Saran
	Fluorosilicone rubber	
	GRS (Butadiene-styrene-rubber)	
	Phenolic resins	
24.4.3	The following materials have been found non-compatible with dry gaseous perchloryl fluoride:	X
	Alkyd enamel	Polyacrylonitrile
	Alkyd resins	Polyisobutylene
	Butyl rubber (with carbon)	Polystyrene
	Cellulose acetate	Polyurethane
	Dacron	Polyvinyl chloride
	Hypalon; carbon filled	Polyvinyl pyrrolidone
	Melamine formaldehyde	Rayon

Reference

Methyl styrene	Rubber, natural
Neoprene; carbon filled	Rulon
Nylon	Silicone rubber
Orlon	Xylene glycol polyethe
Perfluorobutyl acrylate (carbon filled)	

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SECTION 25 - PROPYL NITRATE, NORMAL

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Reference

25.0	PROPYL NITRATE, NORMAL (n-propyl nitrate)	
25.1	The commercial grade is 96 to 98 percent n-propyl nitrate, $C_3H_7NO_3$, and 2 to 4 percent secondary butyl and amyl nitrates, with less than 0.1 percent of other compounds.	
25.2	Nature	
25.2.1	Relatively noncorrosive, n-propyl nitrate is an excellent solvent for organic materials.	C
25.2.2	At high temperatures it will serve as a monopropellant.	C
25.2.3	n-propyl nitrate is soluble in most ordinary polar solvents, such as the lower alcohols and ethers.	C
25.2.4	When deaerated, n-propyl nitrate is not sensitive to mechanical shock. In general use, entrained bubbles create an explosion hazard, as their sudden high compression may raise the temperature enough to cause the adjacent liquid to decompose rapidly.	C
25.2.5	Gases used for pressurization in handling and transfer operations must be inert, and pressurization must be applied slowly.	C
25.2.6	In the absence of air and at moderate temperatures and pressures, liquid n-propyl nitrate is very stable.	C
25.2.7	Either vapor or liquid n-propyl nitrate in air is very easily ignited. Being a monopropellant, once ignited, it will burn when the surroundings are above its autoignition temperature, even if air or oxygen is excluded. It can also burn with an oxidizer or in air.	C
25.3	Metals Compatibility	
25.3.1	Stainless steel and aluminum are compatible with n-propyl nitrate.	C
25.3.2	Mild steel is also compatible, except in the presence of moisture.	C

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	<u>Reference</u>
25.3.3 Copper, brass, and magnesium have been satisfactorily used with this propellant, although a thin green coating usually forms on the copper and brass surfaces.	C
25.3.4 The use of all other ferrous and non-ferrous metals, as well as their alloys, is prohibited with n-propyl nitrate.	C
25.4 Nonmetals Compatibility	
25.4.1 The following plastics have been most successfully used:	C
Polyethylene Kel-F Teflon Nylon Melamine resins Bakelite	
25.4.2 The following lubricants are approved for this use:	C
MIL-G-7711A Graphite Molybdenum disulfide Kel-F oil or grease	

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SECTION 26 - UNSYMMETRICAL DIMETHYLHYDRAZINE

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		<u>Reference</u>
26.0	UNSYMMETRICAL DIMETHYLHYDRAZINE, (UDMH)	
26.1	Propellant-grade unsymmetrical dimethylhydrazine is $(\text{CH}_3)_2\text{NNH}_2$, of 98 percent minimum purity, conforming to MIL-D-25601, 5 March 1959.	
26.2	Nature	
26.2.1	UDMH is a clear, mobile liquid of high volatility. It is slightly alkaline and mildly caustic to tissue.	C
26.2.2	UDMH vapor is flammable in air over a very wide range of concentrations; vapors greater than 2 percent in air can be exploded by an electric spark or an open flame.	C
26.2.3	UDMH is hypergolic with some oxidants, such as fuming nitric acids, nitrogen tetroxide, hydrogen peroxide, chlorine trifluoride, and fluorine.	C
26.2.4	Liquid UDMH is not sensitive to shock or friction.	C
26.2.5	UDMH is miscible with water, ethanol, petroleum fuels, and various amine fuels, including ethylene triamine and hydrazine.	V
26.2.6	Carbon dioxide reacts with UDMH to form a salt, and extended exposure of UDMH to air or other carbon dioxide containing gases could lead to eventual salt precipitation.	C
26.3	Metals Compatibility	
26.3.1	In general, UDMH affects materials in much the same manner as hydrazine.	P
26.3.2	The following metals are approved for use:	C, AG
	Nickel (ambient temperature)	
	Monel	
	Stainless Steel Types 303, 304, 321, 347	
	Stainless Steel 316 (limited to 160°F)	
	Aluminum	

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		Reference
26.3.3	Aluminum and its alloys are satisfactory for this service, but it has been noted that aluminum is attacked to some extent by dilute aqueous solutions of UDMH; the attack being in direct proportion to the amount of water present. UDMH typically contains about 0.1 percent water.	C, P
26.3.4	Aerobraze-I, C-62, and Easy Flow No. 45 silver-solder appear to be satisfactory for use in brazing applications.	C
26.3.5	The use of copper and high copper alloys is prohibited in UDMH transfer and storage equipment.	C
26.3.6	The use of thermometers, manometers, etc., under circumstances that might allow mercury to enter into the UDMH system must be avoided. Mercury and UDMH may react to form explosive (azide-type) products.	C
26.4	Nonmetals Compatibility	
26.4.1	The best materials for use with UDMH include Teflon, unplasticized Kel-F, polyethylene, and Garlock gasket 900.	C
26.4.2	The following additional materials have been found compatible with UDMH:	P
	Alathon	
	Haveg 60 (fluran resin)	
	Nylon	
	Glass Pyrex	
	Graphitar #2	
26.4.3	Apiezon L and Reddy Lube 200 are satisfactory lubricants for many applications.	C
26.4.4	Litharge and glycerine paste, X-Pando, and Q-Seal are compatible and can be used for thread compounds and other similar applications.	P
26.4.5	Rockwell-Nordstrom Lubricant 147 and Lubriseal are suitable for some types of service with UDMH.	C

Reference

26.4.6 The following lubricants, if used, may cause decomposition of the UDMH:

P

APS C-407
Parkerlube 6 PB
Molykote
Peraline 12-4

26.4.7 Petroleum and silicone greases do not react, but are dissolved by the UDMH and must not be used.

P

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION
The Boeing Company - Aerospace Group Aerospace Systems Division - Kent Facility P. O. Box 3999, Seattle, Wash. 98124		Unclassified
2b. GROUP		
3. REPORT TITLE		
(6) Materials Compatibility with Liquid Rocket Propellants		
4. DESCRIPTIVE NOTES (Types of report and inclusive dates)		
Final Report		
5. AUTHOR(S) (First name, middle initial, last name)		
J. A. Letos		
6. REPORT DATE		7a. TOTAL NO. OF PAGES
26 February 1970		34
7b. NO. OF REFS		33
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBERS
b. nil		(14) D2-113073-1
c.		
d.		
9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)		

10. DISTRIBUTION STATEMENT All government agencies may obtain copies directly from DDC. The DDC is requested to route all other requests to Boeing for approval.		
R [REDACTED] Approved by [REDACTED] W [REDACTED]		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY	
	nil	

13. ABSTRACT
<p>This document presents hazard documentation in the area of materials compatibility with liquid rocket propellants. The information contained herein has been collected and extracted in part from handbooks, specifications, technical reports, books, journal articles and manuals, to aid the Safety Engineer in the survey of such hazard data.</p> <p style="text-align: right;">eik</p>

DD FORM 1 NOV 65 1473
1473
U3 4802 1030 REV 7/66
PART 1 OF 3

Unclassified

Security Classification

300 (610)

Unclassified

Security Classification

14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	Compatibility Propellant Oxidizer Hazard Safety Materials Metals Nonmetals						

DD FORM 1 NOV 65 1473
U3 4802 103G REV 7 66
PART 2 OF 3

Unclassified

Security Classification